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Orihara et al.

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(54) **ANTENNA APPARATUS AND COMMUNICATION APPARATUS**

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H01Q 7/06 (2006.01)
H01Q 1/24 (2006.01)
(Continued)

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CPC ***H01Q 7/06*** (2013.01); ***G06K 7/10237*** (2013.01); ***H01Q 1/2208*** (2013.01); ***H01Q 1/243*** (2013.01)

(58) **Field of Classification Search**
CPC H01Q 1/243; H01Q 1/2208; H01Q 7/06; G06K 7/10237; G06K 19/07; G06K 19/077
USPC 343/702, 788
See application file for complete search history.

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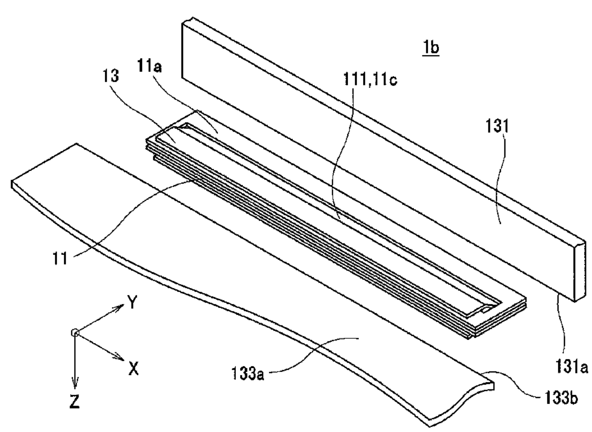
(74) *Attorney, Agent, or Firm* — Oliff PLC

(57) **ABSTRACT**

The present invention provides an antenna apparatus which can realize favorable communication properties while achieving downsizing of a casing of an electronic device when incorporated in an electronic device. An antenna module (**1***a*) which is incorporated in a mobile phone (**130**) and which is enabled to perform communication by receiving a magnetic field transmitted from a reader/writer (**120**) comprises an antenna coil (**11***a*) which is wound in a clearance (**132**) between an end portion (**133***b*) of a metallic plate (**133***a*) opposing the reader/writer (**120**) within a casing (**131**) of the mobile phone (**130**) and an inner peripheral wall (**131***a*) of the casing (**131**) so as not to surround an outer peripheral portion of the metallic plate (**133***a*) and which is inductively coupled with the reader/writer (**120**).

10 Claims, 17 Drawing Sheets



(51) **Int. Cl.**
H01Q 1/22 (2006.01)
G06K 7/10 (2006.01)

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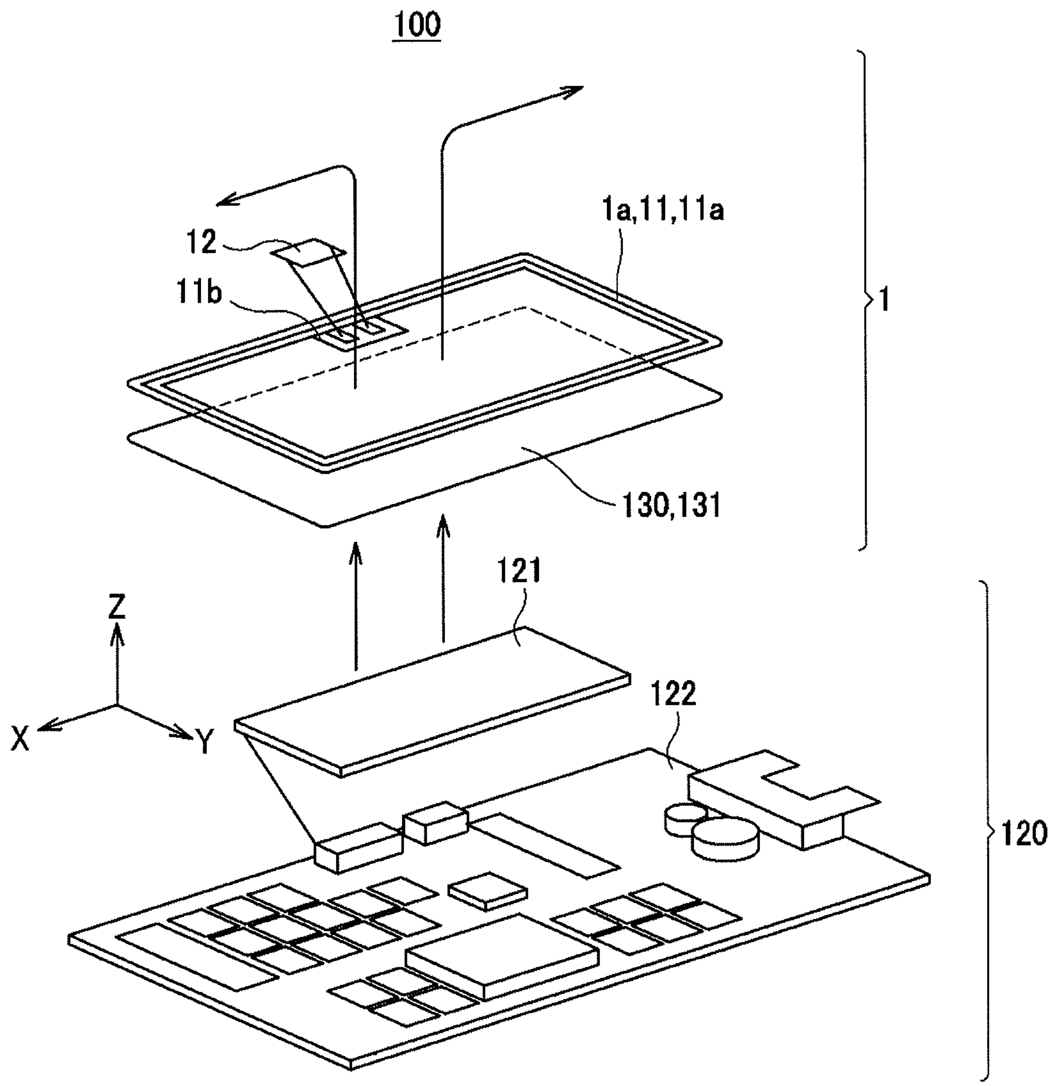


FIG.1

FIG.2A

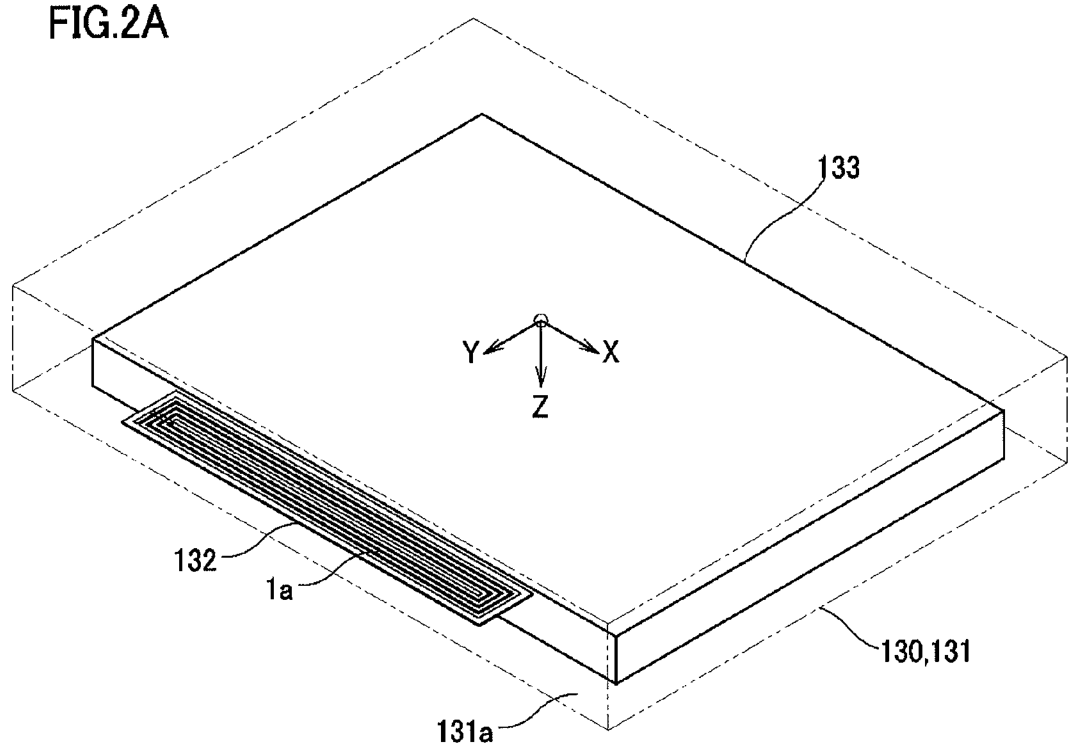
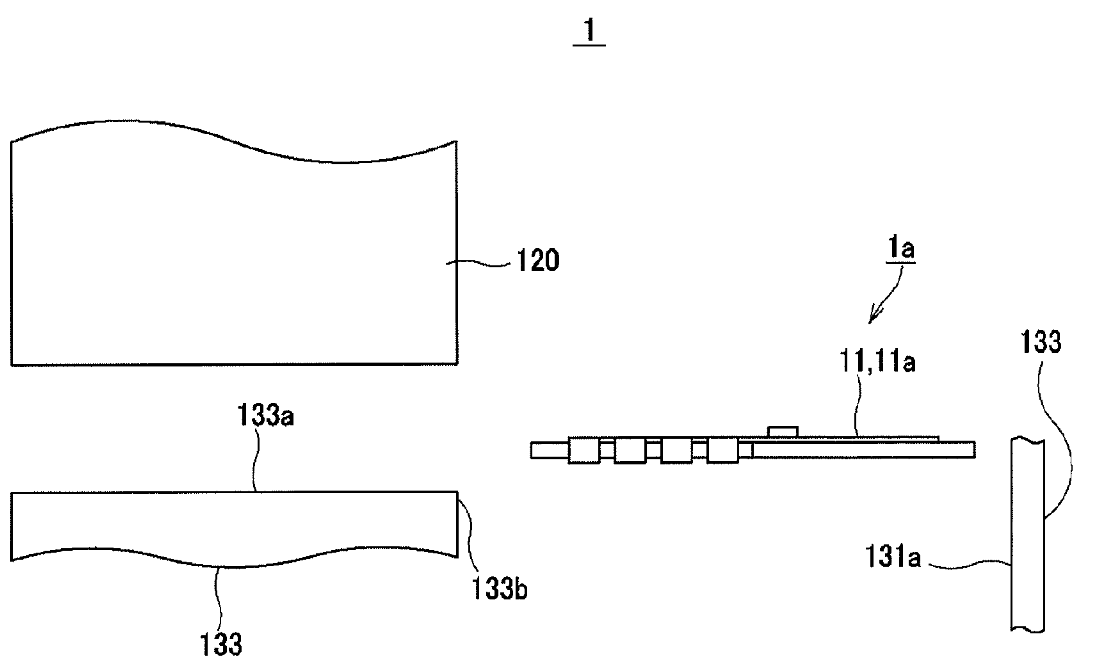

133
Y
X
Z
132
1a
130,131
131a

FIG.2B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133
11,11a
133a
133b
133
131a

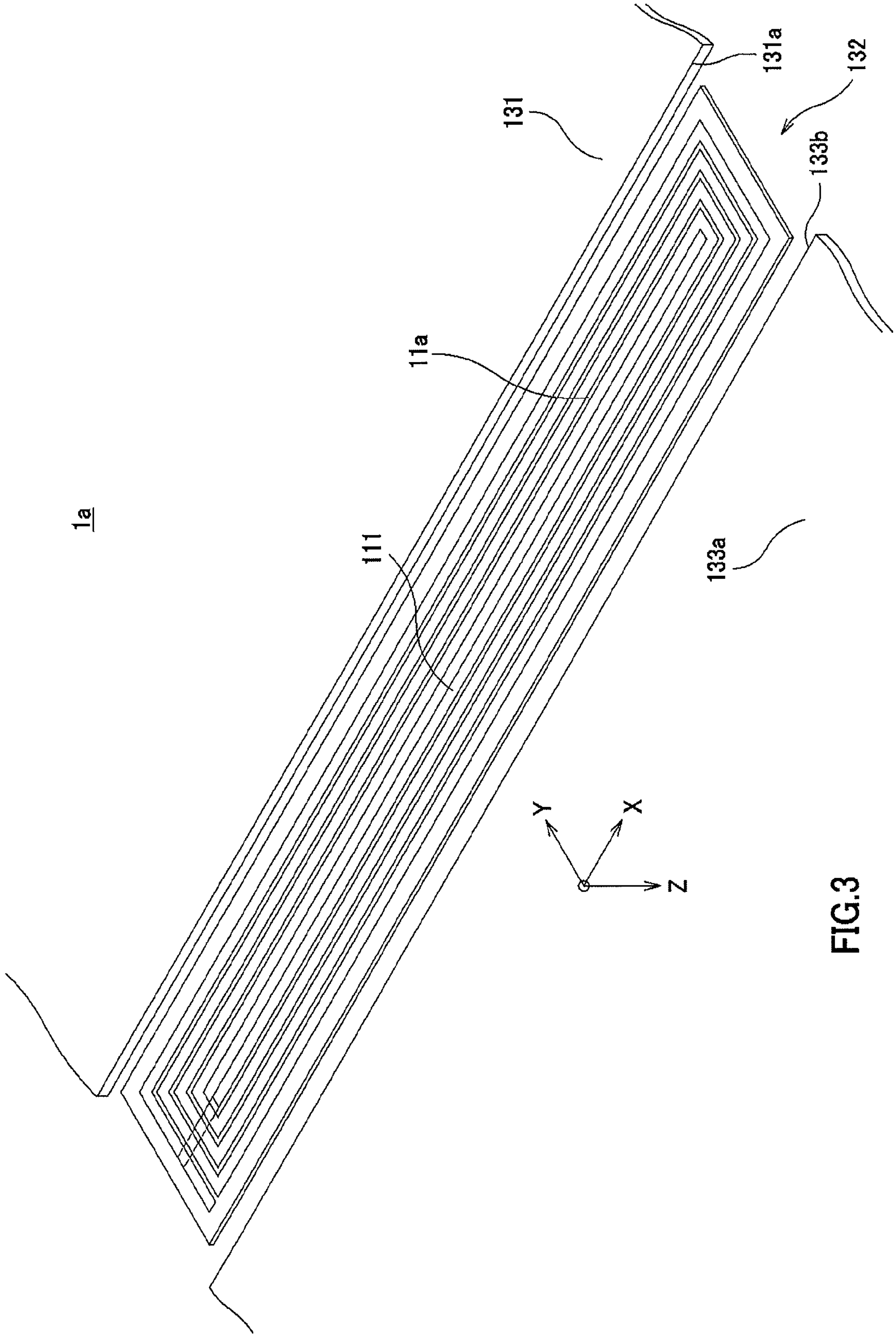


FIG.3

FIG.4A

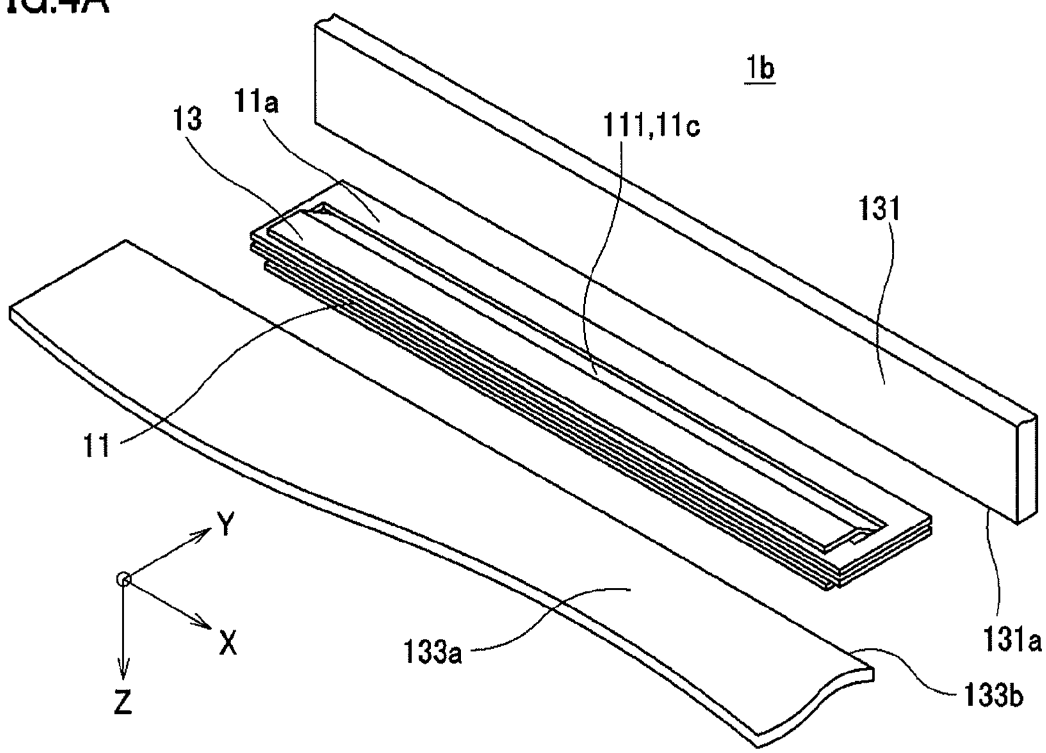
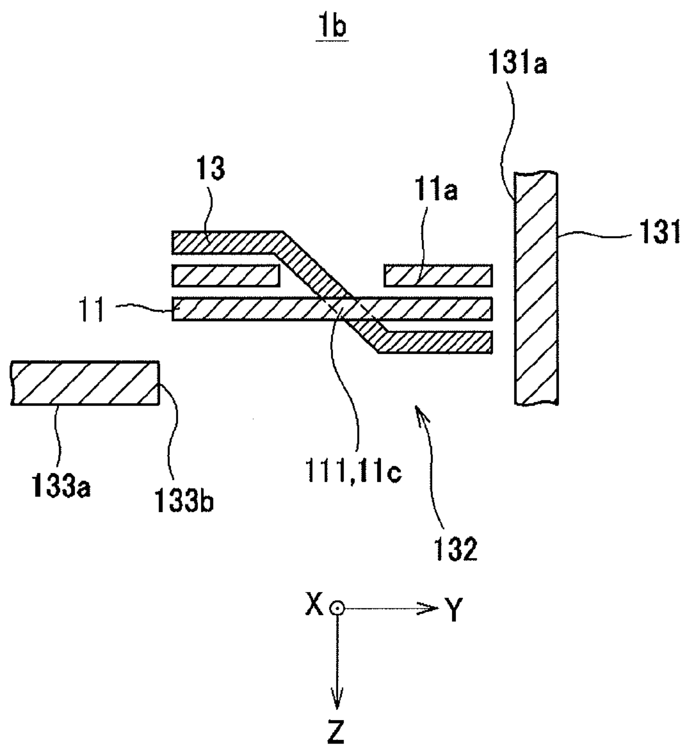

1b
13
11a
111,11c
131
11
Y
X
Z
133a
131a
133b

FIG.4B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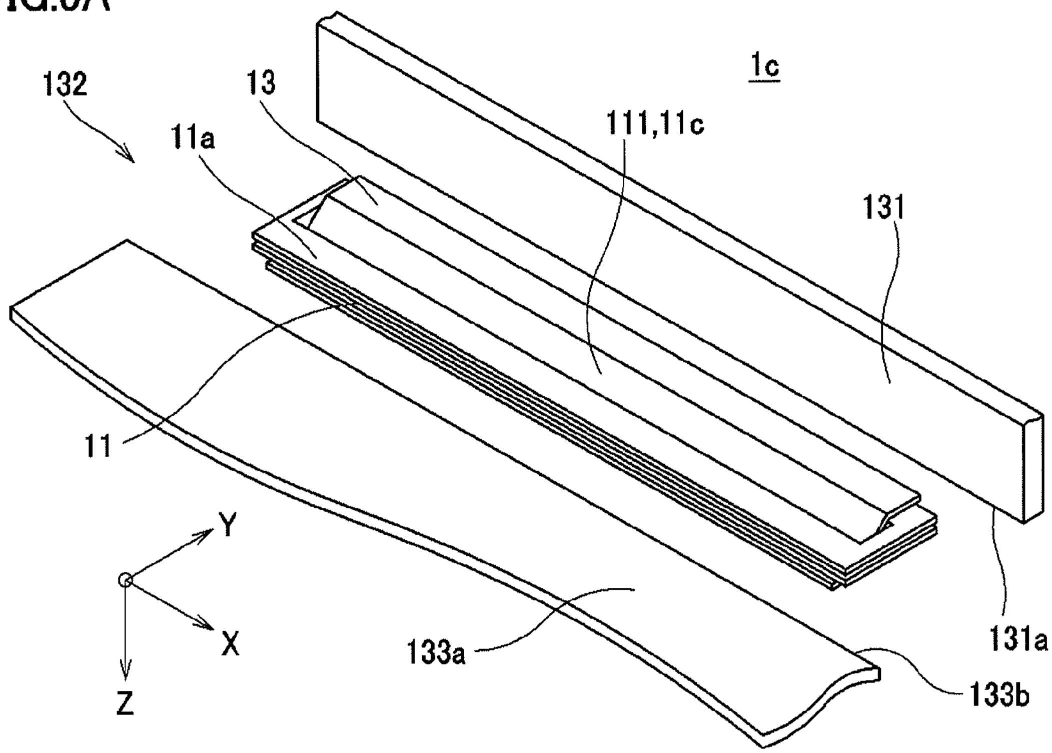
131a
13
11a
131
11
133a
133b
111,11c
132
X
Y
Z

FIG.5A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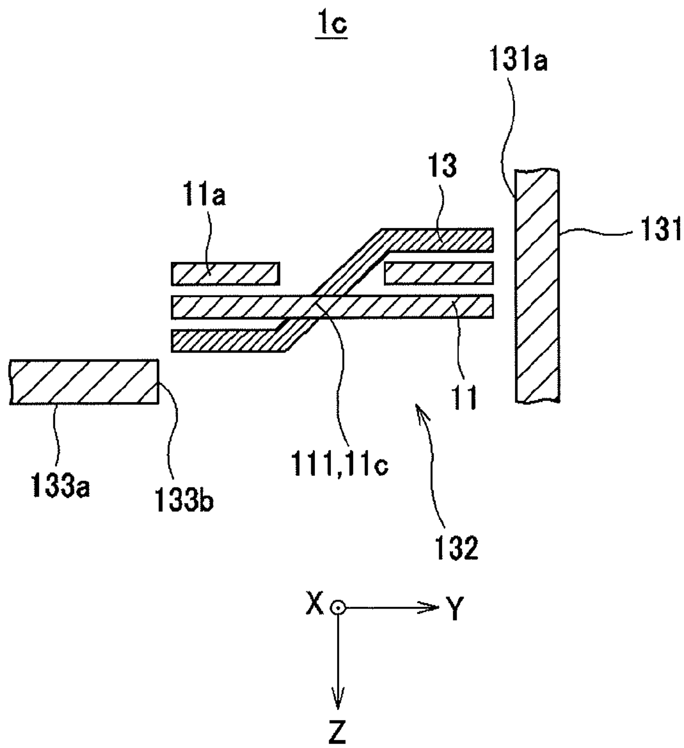
132
13
11a
111,11c
131
11
Y
X
Z
133a
131a
133b

FIG.5B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11
133a
133b
111,11c
132
X
Y
Z

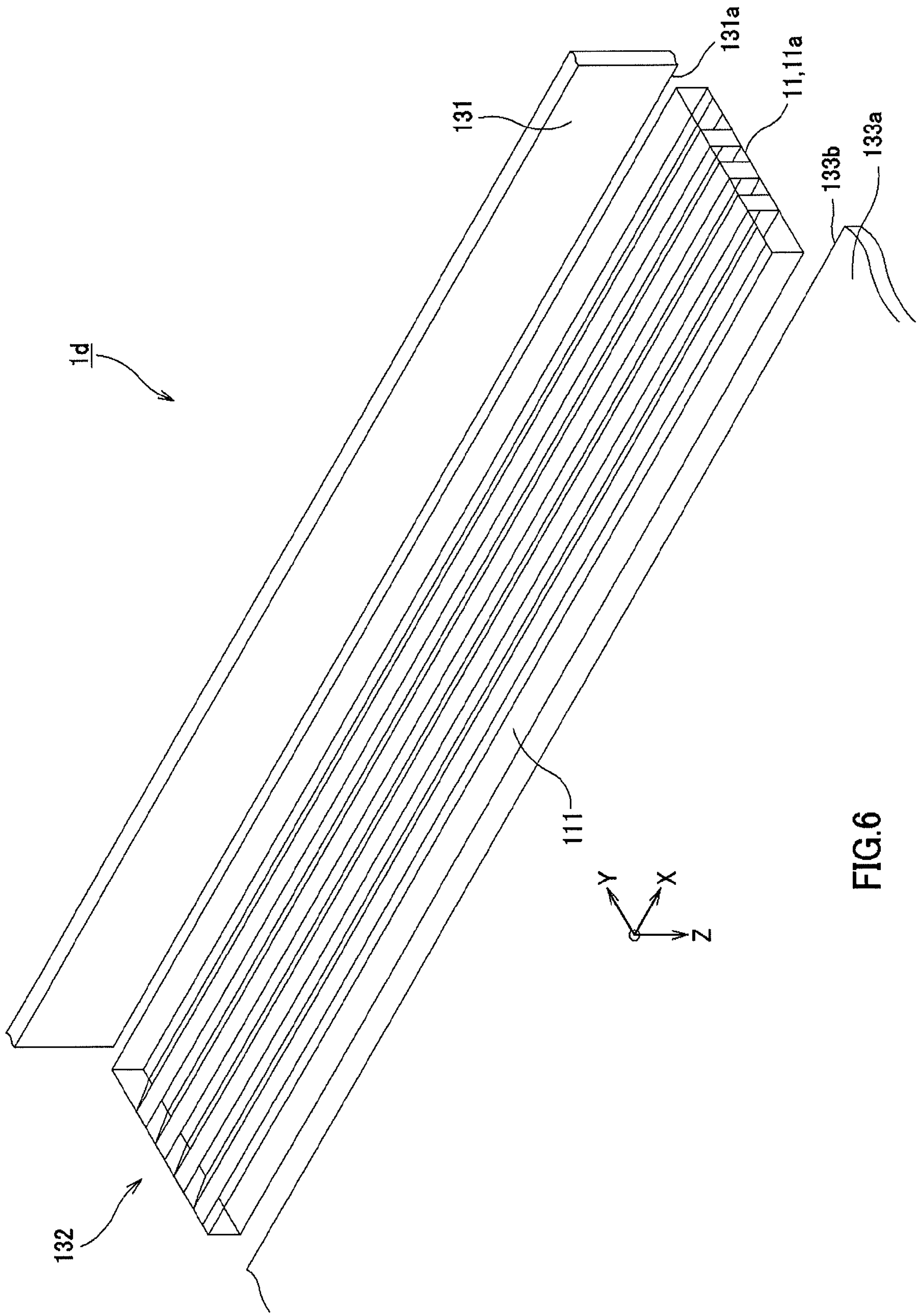
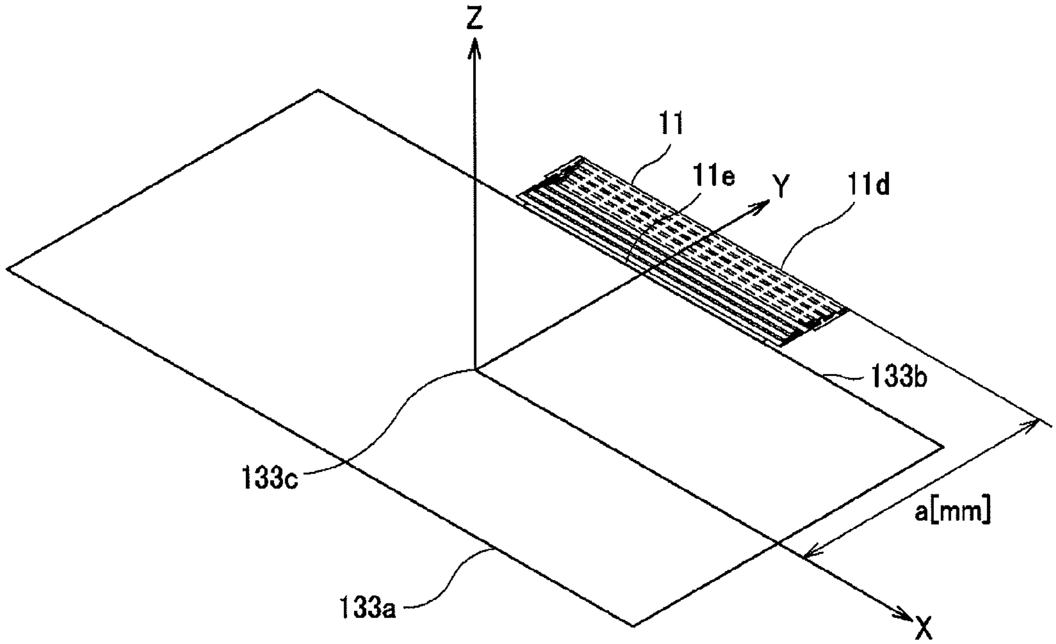


FIG.6



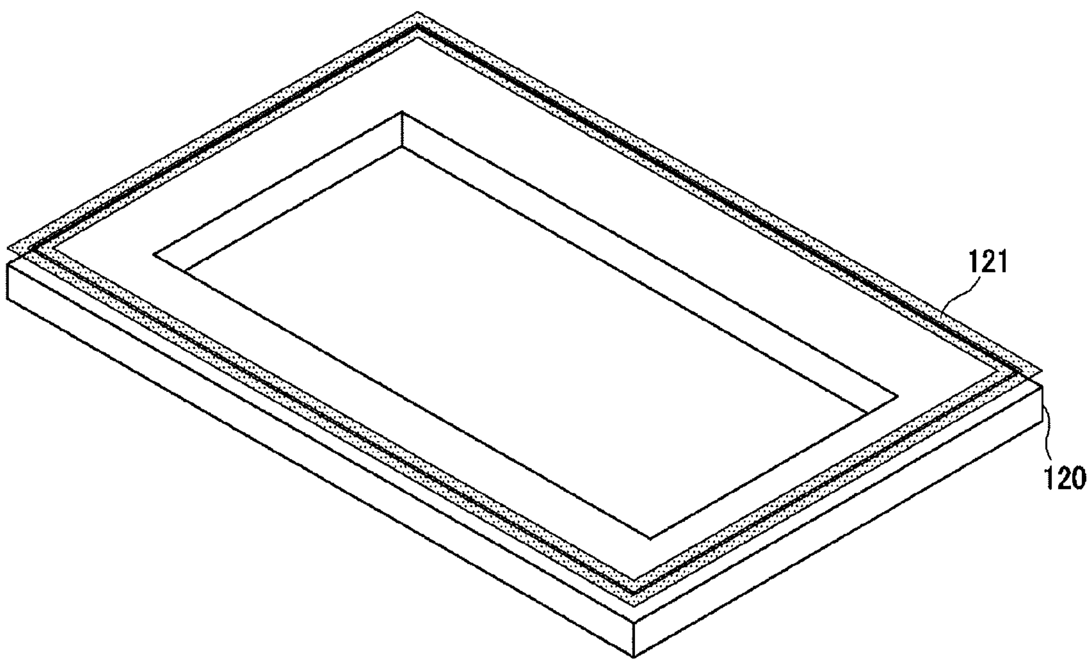
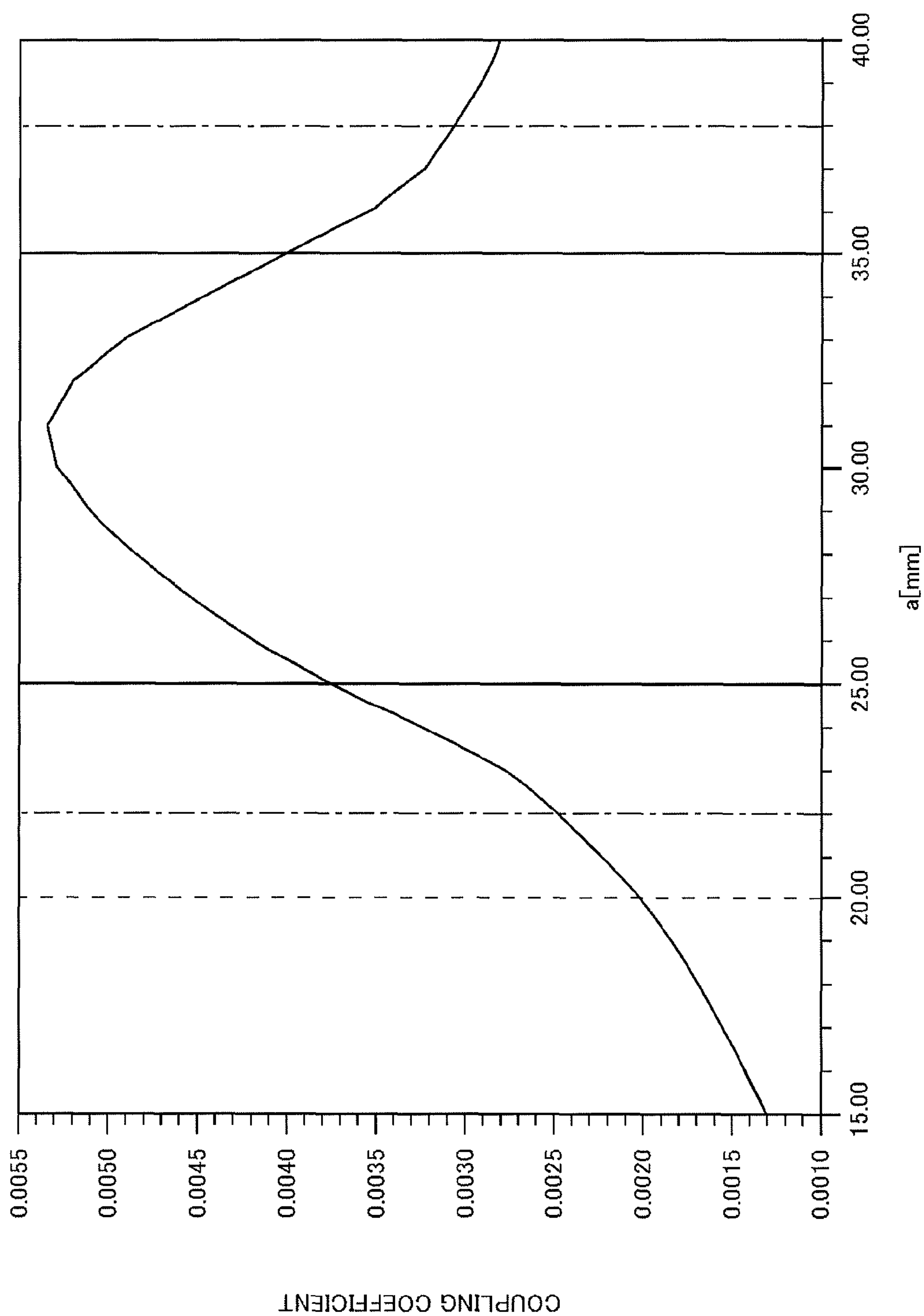


FIG.7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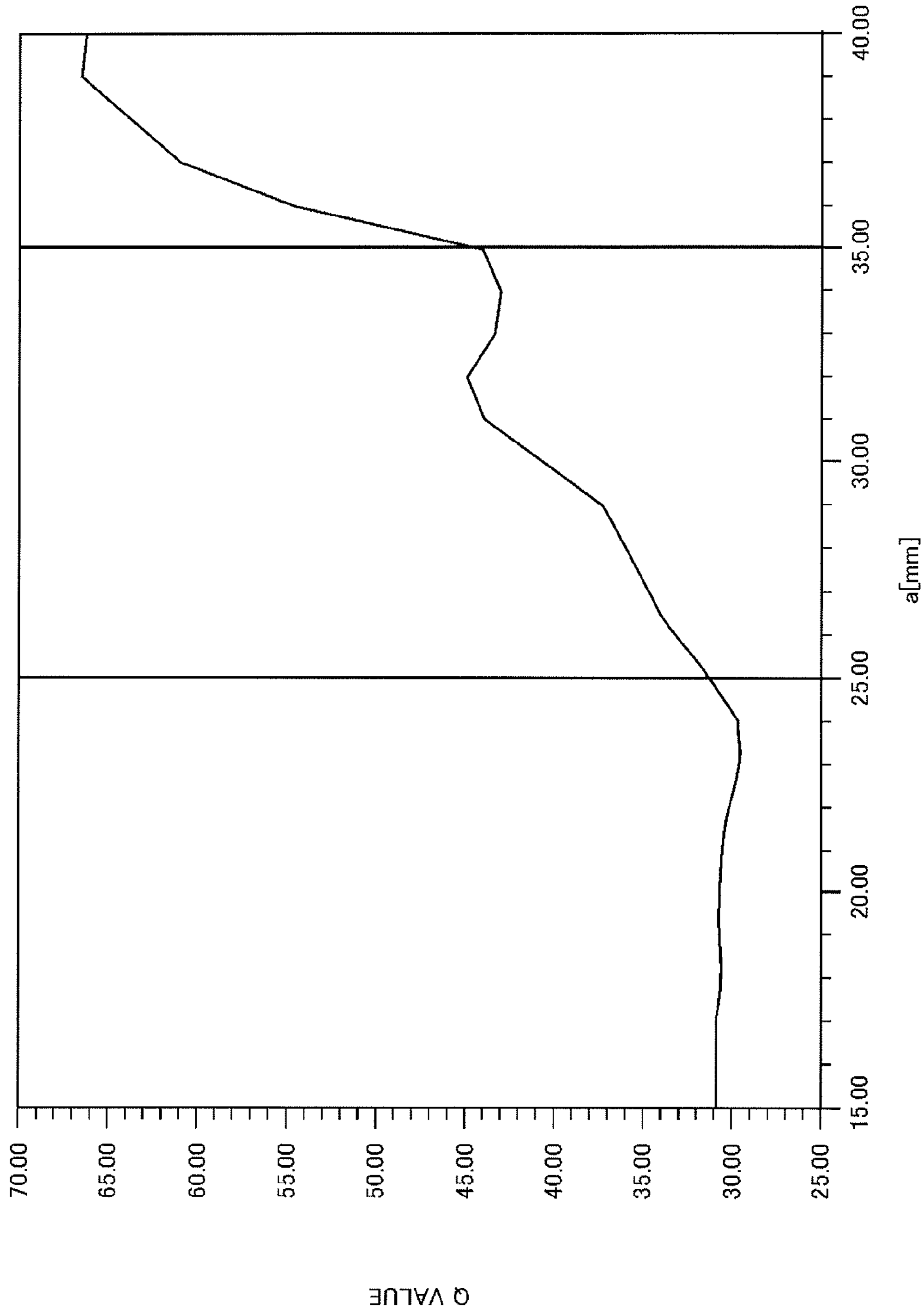
15.00
20.00
25.00
30.00
35.00
40.00
a[mm]

FIG. 8


Q VALUE
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65.00
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35.00
40.00

FIG. 9

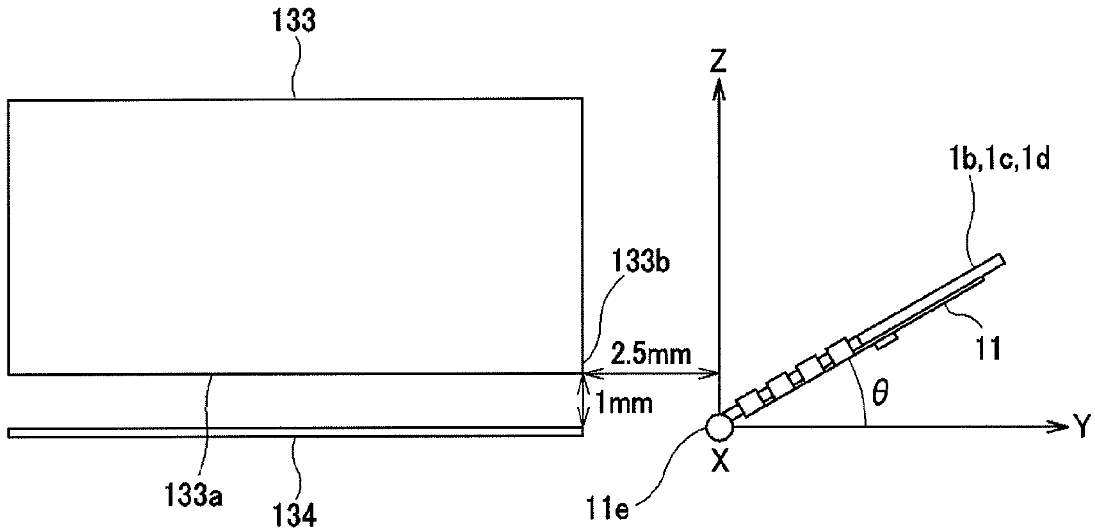
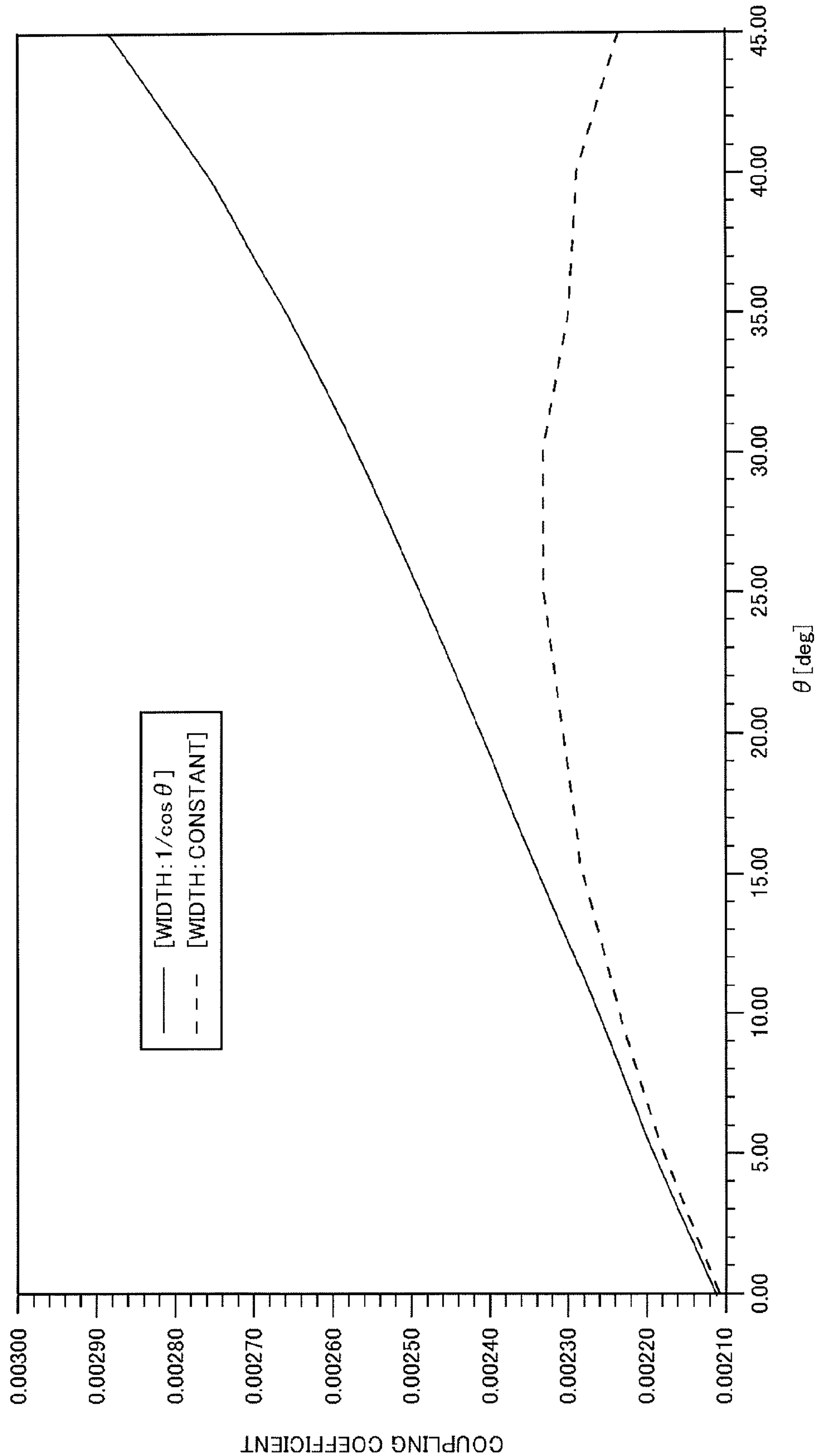
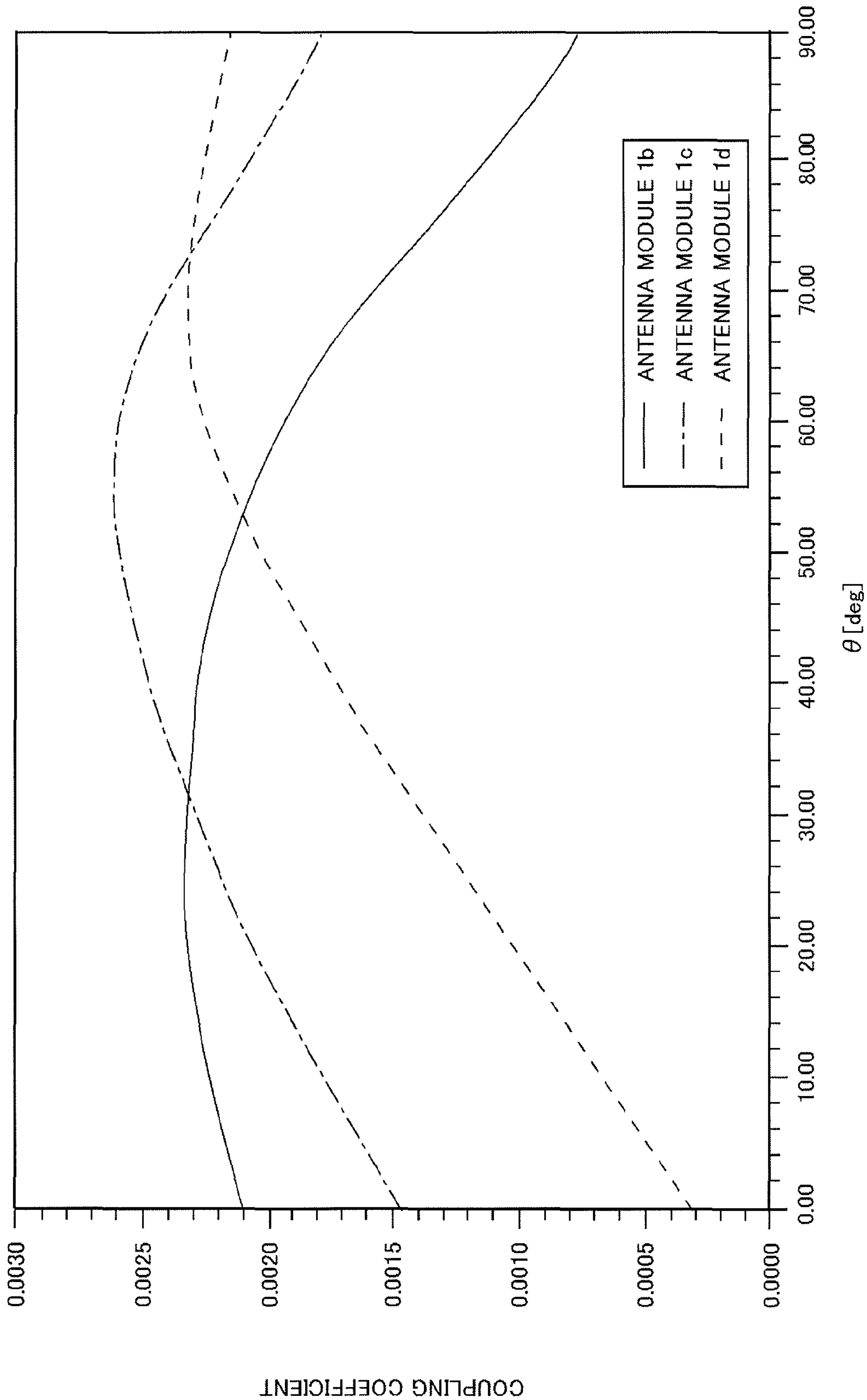


FIG.10



COUPLING COEFFICIENT
0.00300
0.00290
0.00280
0.00270
0.00260
0.00250
0.00240
0.00230
0.00220
0.00210
θ [deg]
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
[WIDTH: 1/cos θ]
[WIDTH: CONSTANT]

FIG. 11


ANTENNA MODULE 1b
ANTENNA MODULE 1c
ANTENNA MODULE 1d
COUPLING COEFFICIENT
0.0030
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0.0020
0.0015
0.0010
0.0005
0.0000
θ [deg]
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
90.00

FIG. 12

FIG.13A

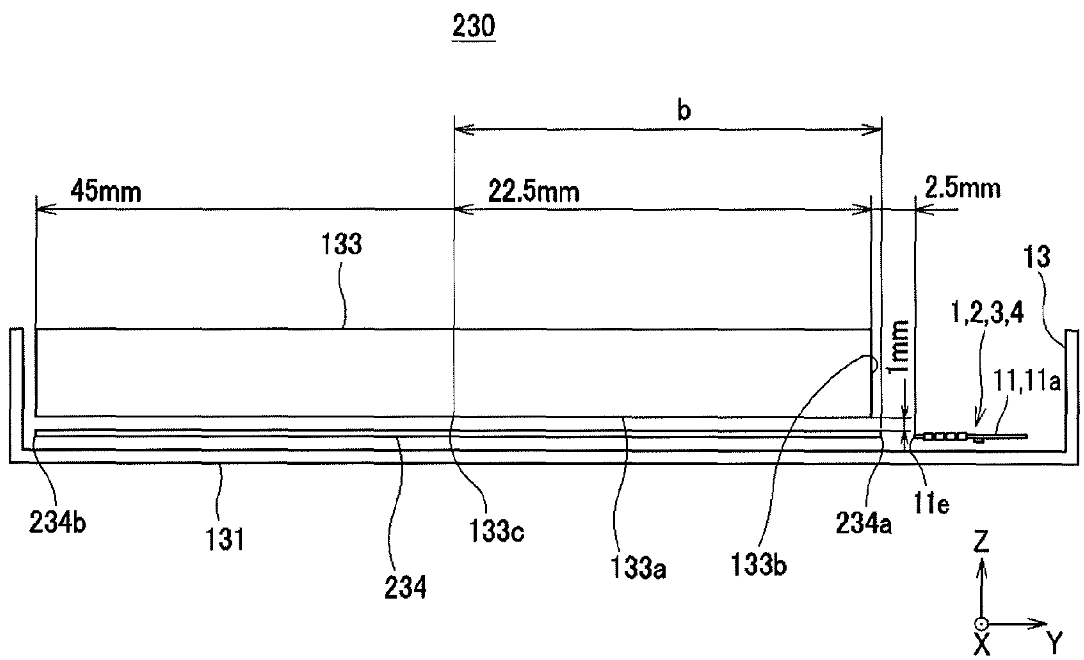
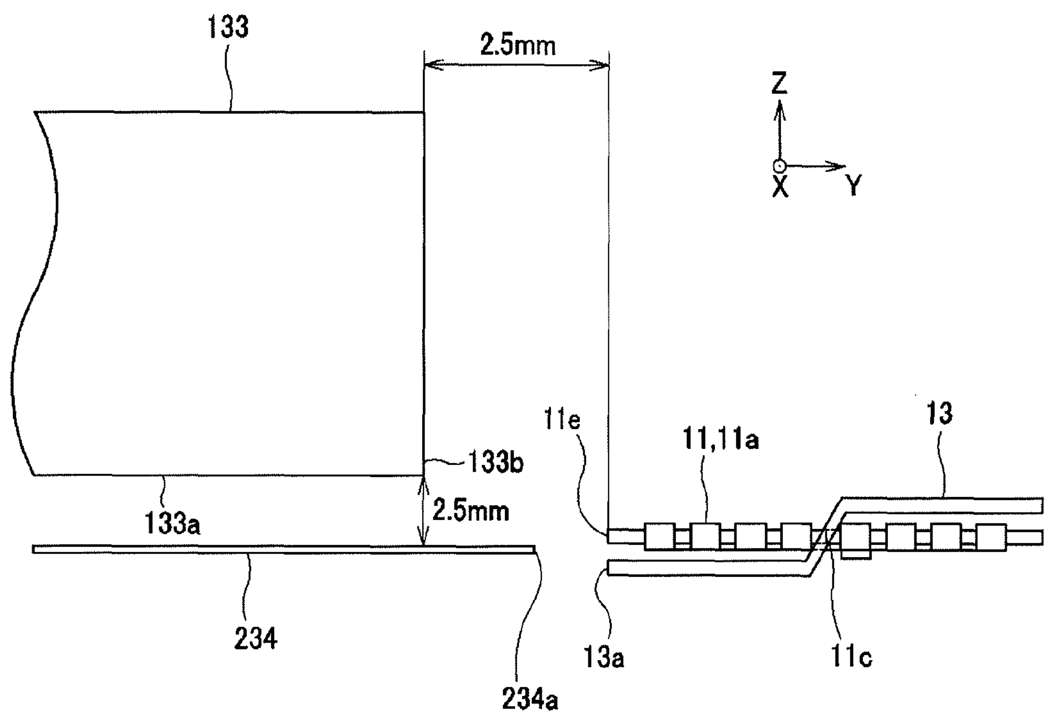
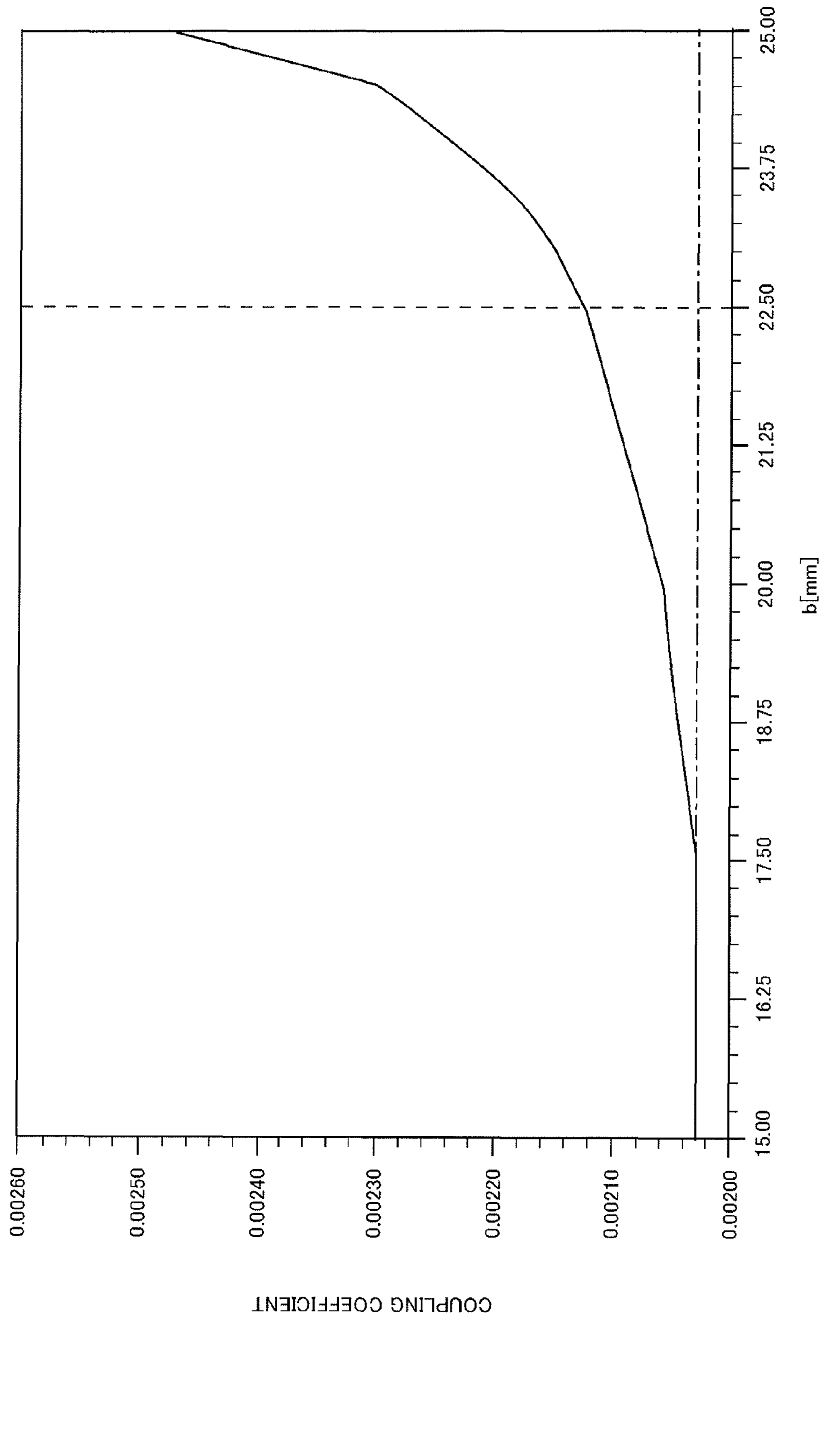


FIG.13B

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0.00240
0.00230
0.00220
0.00210
0.00200
COUPLING COEFFICIENT
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17.50
18.75
20.00
21.25
22.50
23.75
25.00
b[mm]

FIG. 14

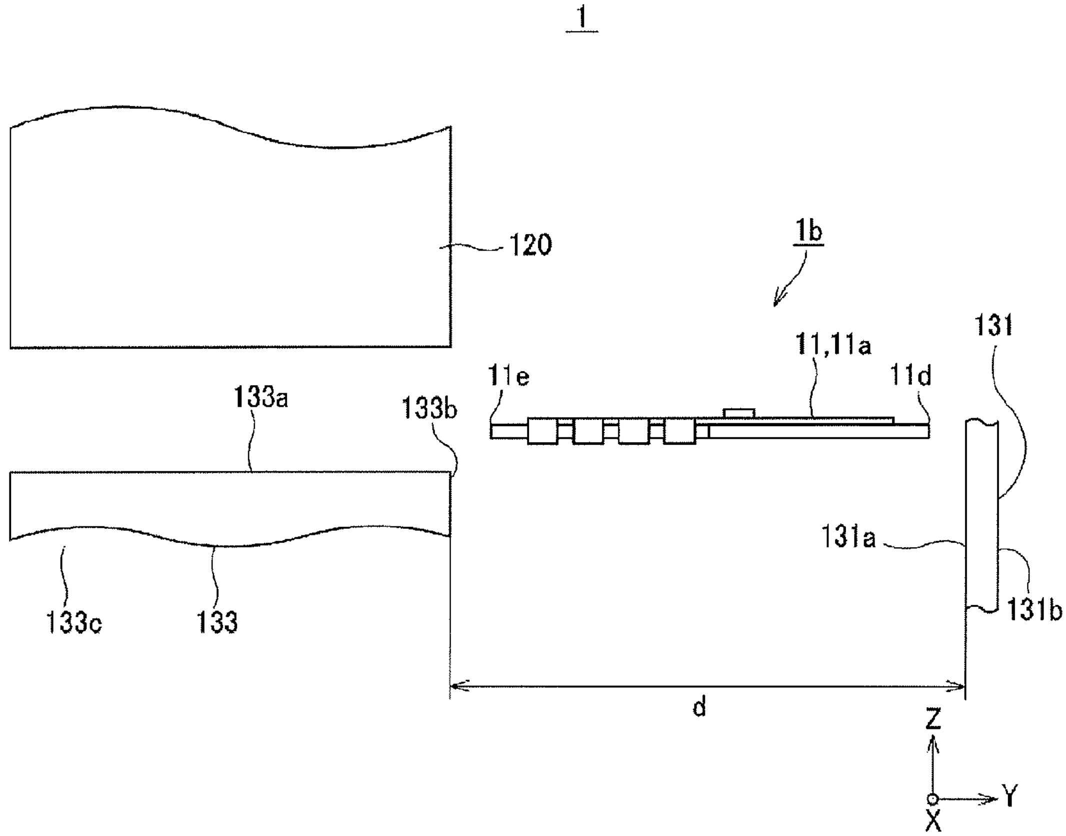


FIG. 15A

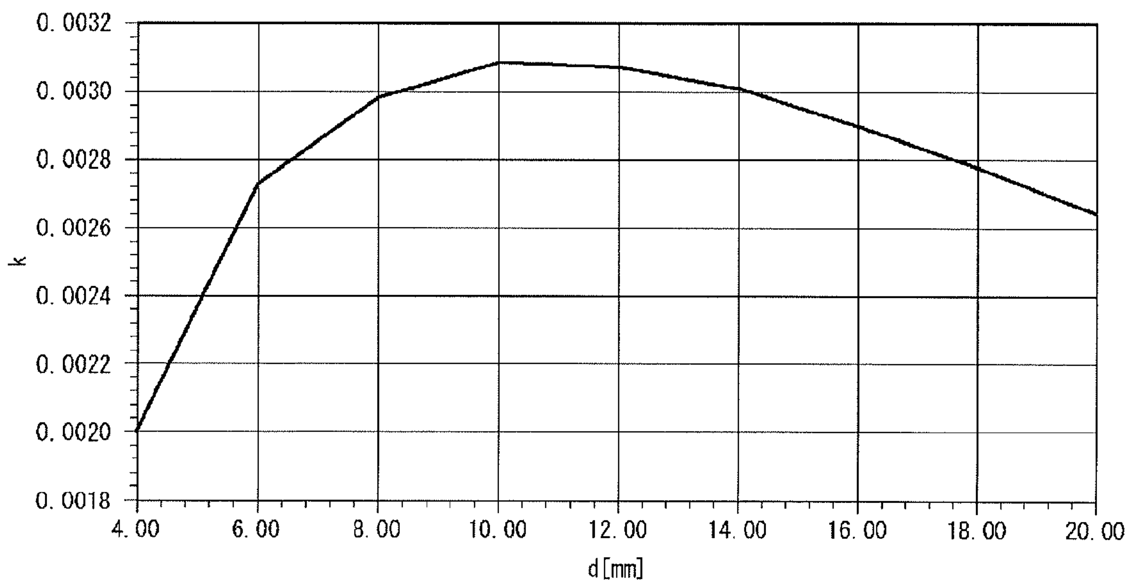


FIG. 15B

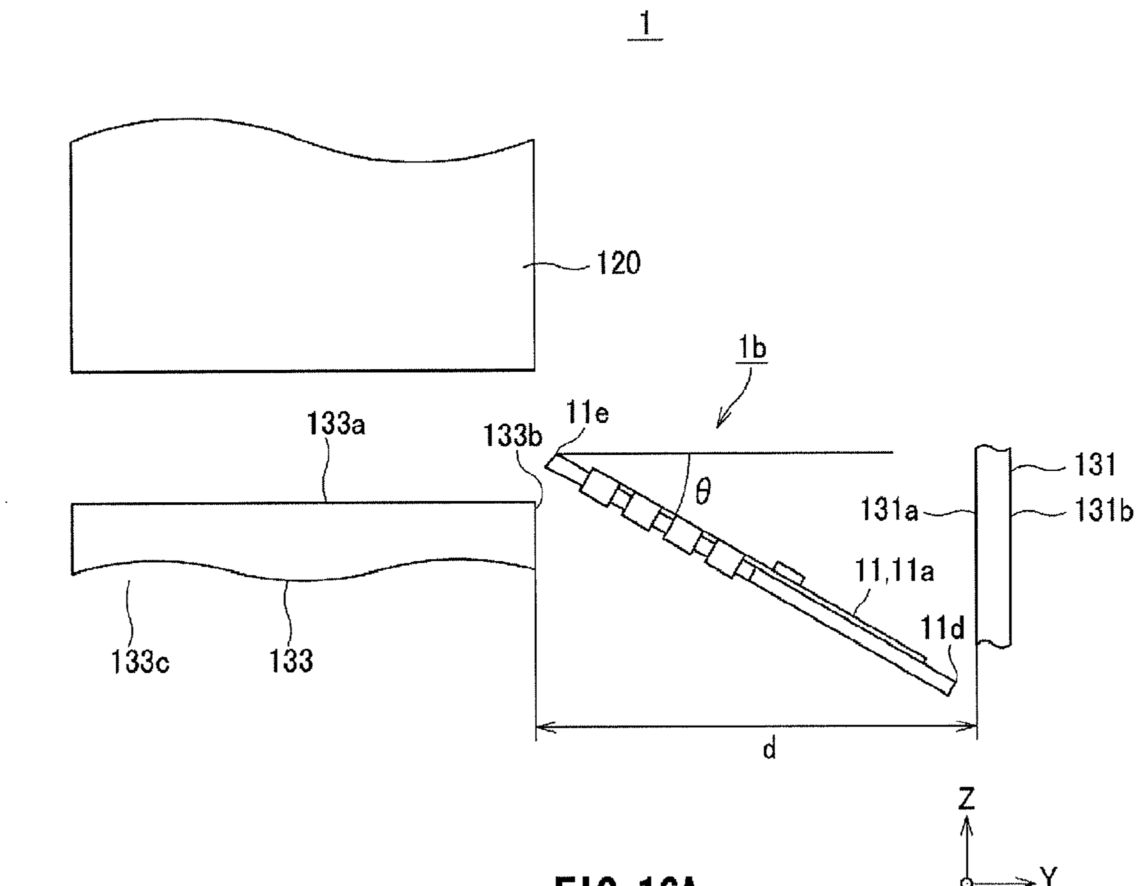


FIG. 16A

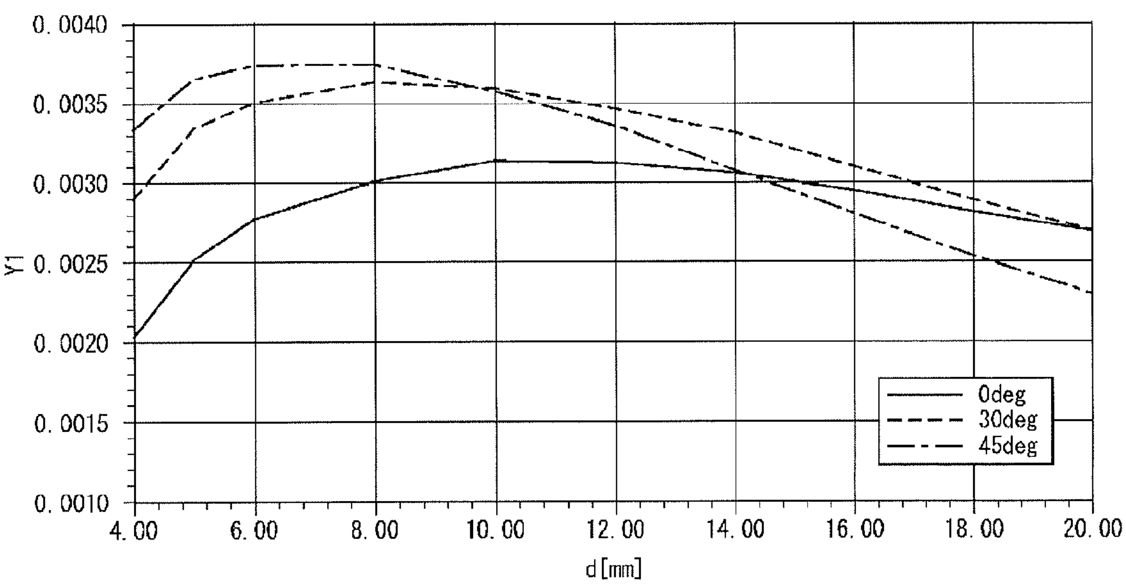


FIG. 16B

FIG. 17A

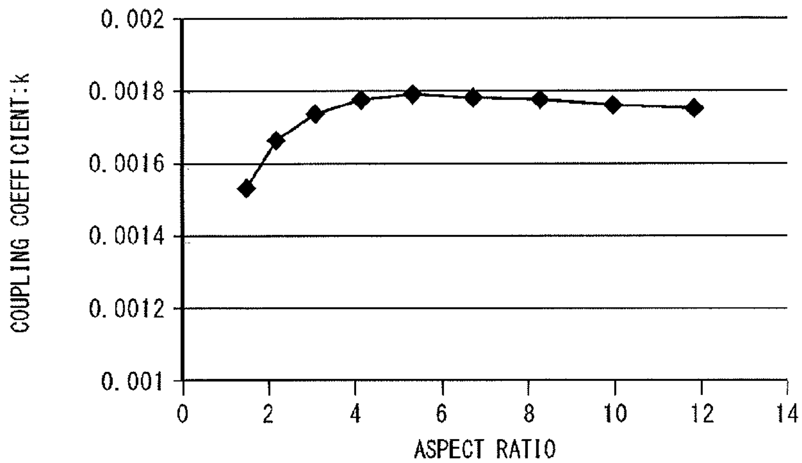


FIG. 17B

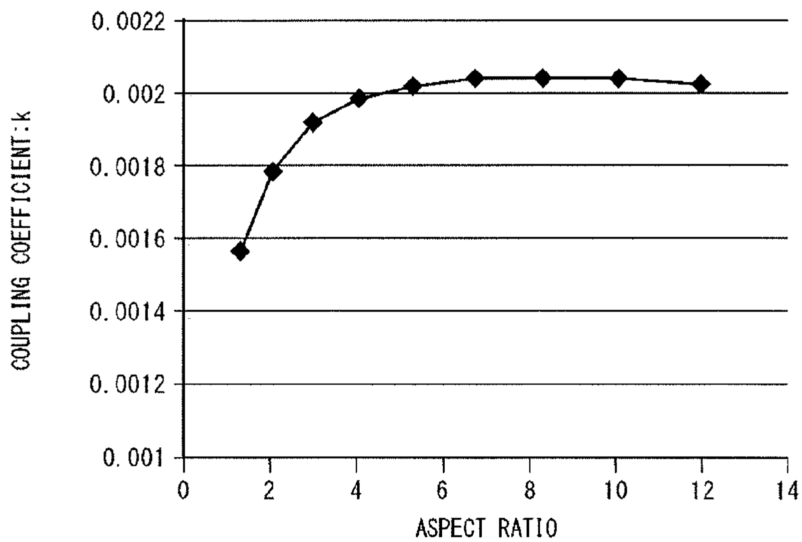
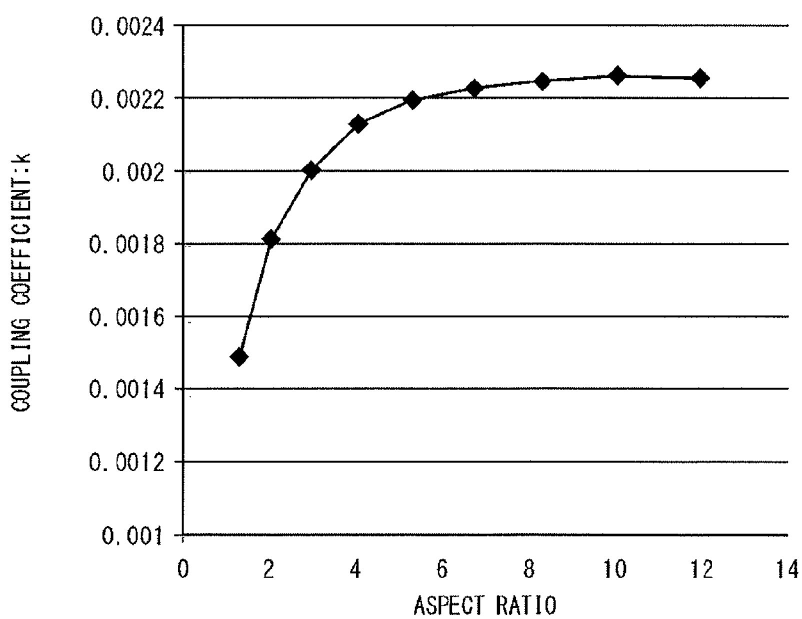


FIG. 17C



ANTENNA APPARATUS AND COMMUNICATION APPARATUS

FIELD OF THE INVENTION

This invention relates to an antenna apparatus and a communication apparatus which is incorporated in an electronic device and which is enabled to perform communication by receiving a magnetic field transmitted from a transmitter.

The present application asserts priority rights based on JP Patent Application 2011-075494 filed in Japan on Mar. 30, 2011 and based on JP Patent Application 2011-260630 filed in Japan on Nov. 29, 2011. The total contents of disclosure of the Patent Applications of the senior filing dates are to be incorporated by reference into the present application.

BACKGROUND OF THE INVENTION

Antenna modules for RFID (Radio Frequency Identification) are used in electronic devices such as mobile phones for installing functions of near field non-contact communication.

Such an antenna module performs communication by utilizing inductive coupling with an antenna coil installed in a transmitter such as a reader/writer. More particularly, when the antenna coil receives a magnetic field from the reader/writer, the antenna module converts the magnetic field into power so as to drive an IC that functions as a communication processing portion.

In order to reliably perform communication, the antenna module is required to receive a magnetic flux of a certain value or more from the reader/writer by using the antenna coil. Therefore, an antenna module according to the prior art is provided with a loop coil in a casing of a mobile phone so as to receive a magnetic flux from the reader/writer by using the coil.

For instance, Patent Document 1 suggests a method in which a flexible cable or a flat cable is disposed around a built-in battery as a method for improving properties of a loop antenna incorporated in a mobile phone apparatus.

PRIOR-ART DOCUMENTS

Patent Document

PTL 1: Japanese Patent Application Laid-Open No. 2005-303541

SUMMARY OF THE INVENTION

The invention as recited in the above Patent Document 1 involved the problem of large fluctuations in resonance frequencies since the antenna was disposed in a clearance within a casing which made it difficult to make the shape of the antenna constant which, in turn, resulted in large variations in inductance.

Particularly in case the antenna was formed by using a flexible cable, the invention as recited in the above Patent Document 1 involved the problem that a large number of manufacturing steps for adjusting the resonance frequency was required since it was difficult to adjust the distributed capacity between wirings.

The present invention has been made in view of such circumstances, and it is an object thereof to provide an antenna apparatus and a communication apparatus which is capable of realizing favorable communication properties while achieving downsizing of a casing of an electronic device when incorporated in an electronic device.

For solving the above-mentioned subjects, in the present invention, an antenna apparatus which is incorporated in an electronic device and which is enabled to perform communication by receiving a magnetic field transmitted from a transmitter comprises an antenna coil which is wound in a clearance between an end portion of a conductive body opposing the transmitter within a casing of the electronic device and an inner peripheral wall of the casing so as not to surround an outer peripheral portion of the conductive body and which is inductively coupled with the transmitter.

Moreover, in the present invention, a communication apparatus which is enabled to perform communication by receiving a magnetic field transmitted from a transmitter comprises an antenna coil which is wound in a clearance between an end portion of a conductive body opposing the transmitter within a casing of the electronic device and an inner peripheral wall of the casing so as not to surround an outer peripheral portion of the conductive body and which is inductively coupled with the transmitter, and a communication processing portion which is driven through current flowing through the antenna coil for performing communication with the transmitter.

Effects of Invention

In the present invention, since the antenna coil is wound in a clearance between an end portion of a conductive body opposing a transmitter within a casing of an electronic device and an inner peripheral wall of the casing so as not to surround an outer peripheral portion of the conductive body, it is possible to achieve downsizing of the casing of the electronic device when it is incorporated in the electronic device. Further, the present invention is capable of realizing favorable communication properties by utilizing magnetic properties of a conductive body opposing a transmitter.

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1** is a view for explaining a structure of a radio communications system incorporating an antenna module adopting the present invention.

FIG. **2**A is a perspective view for explaining an arrangement of an antenna apparatus adopting the present invention. FIG. **2**B is a sectional view for explaining the arrangement of the antenna apparatus adopting the present invention.

FIG. **3** is a view for explaining a configuration of the antenna module adopting the present invention.

FIG. **4**A is a perspective view for explaining a configuration of the antenna module adopting the present invention. FIG. **4**B is a sectional view for explaining the configuration of the antenna module adopting the present invention.

FIG. **5**A is a perspective view for explaining a configuration of the antenna module adopting the present invention. FIG. **5**B is a sectional view for explaining the configuration of the antenna module adopting the present invention.

FIG. **6** is a perspective view for explaining a configuration of the antenna module adopting the present invention.

FIG. **7** is a view for explaining a relative positional relationship between a metallic plate and an antenna substrate.

FIG. **8** is a view showing coupling coefficients of the antenna coil according to Example 1 when the relative positional relationship of the metallic plate and the antenna substrate is changed.

FIG. **9** is a view showing Q values of the antenna coil according to Example 1 when the relative positional relationship of the metallic plate and the antenna substrate is changed.

FIG. **10** is a view for explaining a configuration when an angle θ for inclining the antenna substrate **11** with respect to a surface xy opposing a reader/writer **120** is changed.

FIG. **11** is a view for explaining coupling coefficients of the antenna coil when the angle θ for inclining the antenna substrate **11** with respect to the surface xy opposing the reader/writer **120** is changed.

FIG. **12** is a view for explaining coupling coefficients of the antenna coil when the angle θ for inclining the antenna substrate **11** with respect to the surface xy opposing the reader/writer **120** is changed.

FIG. **13**A and FIG. **13**B are views for explaining a communication apparatus according to Example 2 adopting the present invention.

FIG. **14** is a view for explaining coupling coefficients of the antenna coil when the relative positional relationship between an end portion of a magnetic sheet superposing the metallic plate and the antenna coil is changed.

FIG. **15**A and FIG. **15**B are views for explaining changes in communication properties in accordance with dimensions of the antenna coil.

FIG. **16**A and FIG. **16**B are views for explaining changes in communication properties in accordance with dimensions of the antenna coil.

FIG. **17**A, FIG. **17**B and FIG. **17**C are views showing changes in coupling coefficients when the ratio of a width in a y axial direction of the antenna coil to a width in an x axial direction of the antenna coil is changed.

DETAILED DESCRIPTION OF THE INVENTION

Forms of embodying the present invention will now be explained in details while referring to the drawings. It should be noted that the present invention is not to be limited to the following embodiments alone but that various changes are possible without departing from the gist of the present invention.

The communication apparatus adopting the present invention is an apparatus which is incorporated in an electronic device and which is enabled to perform communication by receiving a magnetic field transmitted from a transmitter, and is used, for instance, by being incorporated in a radio communication system **100** for RFID (Radio Frequency Identification) as shown in FIG. **1**.

The radio communication system **100** is comprised of a communication apparatus **1** and a reader/writer **120** which performs access to the communication apparatus **1**. Here, the communication apparatus **1** and the reader/writer **120** shall be disposed to oppose each other in a xy plane of a three-dimensional Cartesian coordinate system xyz.

The reader/writer **120** functions as a transmitter for transmitting a magnetic field along a z axial direction with respect to the communication apparatus **1** which mutually oppose each other in the xy plane, and more particularly, it comprises an antenna **121** for transmitting a magnetic field towards the communication apparatus **1** and a control substrate **122** which performs communication with the communication apparatus **1** which is inductively coupled via the antenna **121**.

More particularly, the reader/writer **120** is provided with the control board **122** which is electrically connected to the antenna **121**. The control board **122** is mounted with a control circuit comprised of one or more electronic parts such as an integrated circuit chip. The control circuit performs various processes based on data that have been received from the communication apparatus **1**. For instance, when data are to be transmitted to the communication apparatus **1**, the control circuit encodes the data, modulates carrier waves of a specified frequency (for instance, 13.56 MHz) based on the encoded data, amplifies the modulated modulating signals and drives the antenna **121** by using the amplified modulating signal. When data are to be read from the communication apparatus **1**, the control circuit amplifies the modulating signal of the data received by the antenna **121**, demodulates the modulating signal of the amplified data and decodes the demodulated data. In this respect, the control circuit employs encoding methods and modulating methods that are used in general readers/writers examples of which are the Manchester encoding method or the ASK (Amplitude Shift Keying) modulating method.

The communication apparatus **1** comprises an antenna module **1**_a_ being installed, for instance, in an interior of a casing **131** of a mobile phone **130** which is disposed to oppose the reader/writer **120** in the xy plane and having an antenna substrate **11** mounted with an antenna coil **11**_a_ which is enabled to perform communication with the inductively coupled reader/writer **120**, and a communication processing portion **12** which is driven through current flowing through the antenna coil **11**_a_ for performing communication with the reader/writer **120**.

In this respect, the communication processing portion **12** can be driven through power from a battery pack **133** of the mobile phone **130** in which the communication apparatus **1** is installed (to be described later) or from a power supplying portion such as an external power source besides by the antenna coil **11**_a_.

The antenna substrate **11** is mounted with an antenna coil **11**_a_ which is formed through, for instance, patterning processing a flexible conducting wire such as a flexible flat cable and with a terminal portion **11**_b_ for electrically connecting the antenna coil **11**_a_ and the communication processing portion **12**.

Upon receiving a magnetic field transmitted from the reader/writer **120**, the antenna coil **11**_a_ is magnetically coupled to the reader/writer **120** through inductive coupling, receives modulated electromagnetic waves and supplies a received signal to the communication processing portion **12** through the terminal portion **11**_b_.

The communication processing portion **12** is driven through current flowing through the antenna coil **11**_a_ and performs communication with the reader/writer **120**. More particularly, the communication processing portion **12** demodulates the received modulating signal, decodes the demodulated data and writes the decoded data to an internal memory provided in the communication processing portion **12**. The communication processing portion **12** further reads data to be transmitted to the reader/writer **120** from the internal memory, encodes the read data, modulates the carrier waves based on the encoded data and transmits the modulated radio waves to the reader/writer **120** through the antenna coil **11**_a_ which has been magnetically coupled through inductive coupling.

EXAMPLE 1

The structure of the antenna module **1**_a_ in the radio communication system **100** having the above-described structure will now be explained as Example 1.

In view of achieving downsizing of an electronic device when installed in an electronic device such as a mobile phone **130** and realizing favorable communication properties with the reader/writer **120**, the antenna coil **11**_a_ of the antenna module **1**_a_ according to Example 1 is disposed, for instance, on an xy plane of a three-dimensional Cartesian coordinate system xyz as shown in FIG. **2**A in a clearance **132** between a battery pack **133** provided within a casing **131** of the mobile phone **130** and an inner peripheral wall **131***a* of the casing **131**.

In this respect, the antenna module according to Example 1 can also be disposed, for instance, in a clearance between a conductive body such as an integrated circuit board disposed inside the casing **131** and the inner peripheral wall of the casing besides the above-mentioned case in which it is disposed in the clearance **132** between the battery pack **133** and the inner peripheral wall **131***a* of the casing **131**. In the present example, explanations will be made based on a case in which the antenna module is disposed as a plate-like conductive body between an end portion **133***b* of a metallic plate **133***a* opposing the reader/writer **120** which is a metallic casing of the battery pack **133** as shown in FIG. **2**B and the inner peripheral wall **131***a* of the casing **131** as a matter of convenience.

Here, as shown in the sectional view of FIG. **2**B, the metallic plate **133***a* which is a metallic casing of the battery pack **133** disposed in the mobile phone **130** carries electricity in a relatively good manner so that an eddy current is generated upon addition of an alternating magnetic field from the exterior so as to reject the magnetic field. In examining a magnetic field distribution in case such an alternating magnetic field is added from the exterior, it exhibits properties in that the magnetic field of the end portion **133***b* of the metallic plate **133***a* of the battery pack **133** opposing the reader/writer **120** is strong.

For realizing favorable communication properties by utilizing properties of the magnetic field strength in the interior of the casing **131** of the mobile phone **130**, the antenna coil **11***a* of the antenna module **1***a* can be disposed, as shown, for instance, in FIG. **3**, in that a central axis **111** of the antenna coil **11***a* which is parallel to the z axis passes through the clearance **132** between the end portion **133***b* of the metallic plate **133***a* and the inner peripheral wall **131***a* of the casing **131** and in that the coil wire is wound in the clearance **132**.

It is also possible to employ a configuration for antenna modules **1***b*, **1***c* with an antenna coil in which the central axis **111** of the antenna coil **11***a* which is parallel to the z axis passes through the clearance **132** and which is wound in the clearance **132** wherein a magnetic sheet **13** is inserted into a central portion **11***c* of the antenna substrate **11** as shown, for instance, in FIG. **4**A and FIG. **5**A.

Here, the antenna module **1***b* as shown in FIG. **4**A is arranged, as shown in FIG. **4**B, in that the magnetic sheet **13** is inserted into the central portion **11***c* of the antenna coil **11***a* formed on the antenna substrate **11** such that the magnetic sheet **13** is located closer to the reader/writer **120** side than the antenna coil **11***a* on the end portion **133***b* side of the metallic plate **133***a* while the antenna coil **11***a* is located closer to the reader/writer **120** side than the magnetic sheet **13** on the inner peripheral wall **131***a* side of the casing **131**.

Further, the antenna module **1***c* as shown in FIG. **5**A is arranged, as shown in FIG. **5**B, in that the magnetic sheet **13** is inserted into the central portion **11***c* of the antenna coil **11***a* formed on the antenna substrate **11** such that the antenna coil **11***a* is located closer to the reader/writer **120** side than the magnetic sheet **13** on the end portion **133***b* side of the metallic plate **133***a* while the magnetic sheet **13** is located closer to the reader/writer **120** side than the antenna coil **11***a* on the inner peripheral wall **131***a* side of the casing **131**.

Moreover, the antenna coil **11***a* shall be wound such that it does not surround the outer periphery of the metallic plate **133***a*. In other words, it will be sufficient if the coil wire is wound such that the central axis of the antenna coil **11***a* passes through the clearance **132**. For instance, it is possible to employ an antenna module **1***d* having an antenna coil **11***a* which is wound to surround a section which is defined by the xy plane of the antenna substrate **11** disposed in the clearance **132** as shown in FIG. **6** and having a winding direction which is parallel to the inner peripheral wall **131***a*.

In Example 1, evaluations are made using communication properties of antenna module **1***b* from among the above-described four types of antenna modules of different antenna structures. This is because the magnetic sheet **13** of the antenna module **1***b* is disposed such that the magnetic field which is generated around the end portion **133***b* of the metallic plate **133***a* can be effectively drawn into the antenna coil **11***a* in comparison to the other antenna modules **1***a*, **1***c* and **1***d*.

First, as for efficiency evaluation, communication properties are evaluated when the relative positional relationship between the metallic plate **133***a* and the antenna substrate **11** is changed while the metallic plate **133***a* and the reader/writer **120** are made to oppose as shown in FIG. **7**.

Concrete conditions for evaluation were as follows. Namely, the antenna **121** of the reader/writer **120** was a double-wound coil having an external form of 66 m×100 mm defined in xy axial directions. The metallic plate **133***a* was made of stainless steel having a dimension of 100 mm×50 mm×0.3 mm defined in xyz axial directions. The antenna coil **11***a* of the antenna module **1***b* had a configuration with an external form of 40 mm×10 mm defined in xy axial directions and was a fourfold-wound coil. Moreover, the distance from the surface of the metallic plate **133***a* to the surface of the antenna coil **11***a* defined in a z axial direction was set to be 1 mm.

Here, the following value of "a" was used as a value for indicating a relative positional relationship between the metallic plate **133***a* and the antenna substrate **11**. That is, the value of "a" is a distance defined in the y axial direction from the central portion **133***c* of the metallic plate **133***a* to the end portion **11***d* on the inner peripheral wall **131***a* side of the antenna substrate **11**.

Changes in coupling coefficients of the antenna coil **11***a* when the value of a is changed from 15 mm to 40 mm under the above-described condition are shown in FIG. **8** while changes in Q values are shown in FIG. **9**, respectively.

Here, since the width of the metallic plate **133***a* is 50 mm, the end portion **133***b* of the metallic plate **133***a* coincides with the end portion **11***d* on the inner peripheral wall **131***a* side of the antenna coil **11***a* when the value of "a" is 25 mm. Further, since the width of the antenna coil **11***a* is 10 mm, the end portion **11***e* on the metallic plate **133***a* side of the antenna coil **11***a* coincides with the end portion **133***b* of the metallic plate **133***a* when the value of "a" is 35 mm.

As shown in FIG. **8**, the coupling coefficient is highest when the value of "a" is 30 mm and the central portion **11***c* of the antenna substrate **11** substantially coincides with the end portion **133***b* of the metallic plate **133***a*, and reduces when the value of "a" separates from 30 mm. The coupling coefficients exhibit substantially identical properties when the value of "a" is 25 mm and 35 mm. The reason why coupling coefficients are high when the antenna coil **11***a* is disposed proximate of the end portion **133***b* of the metallic plate **133***a* is that the magnetic flux density is high in the periphery of the end portion **133***b* of the metallic plate **133***a*. Further, an eddy current is generated on the metallic plate **133***a* upon receiving a magnetic field transmitted from the reader/writer **120** due to the fact that the magnetic field intensity at the end portion **133***b* is larger than that at the central portion **133***c* so that the magnetic energy that is received from the reader/writer **120** can be effectively transmitted to the antenna coil **11***a* side.

In comparing a case in which the value of "a" is changed to become smaller than 25 mm to a case in which the value of "a" is changed to become larger than 35 mm, while the coupling coefficients reduce in both cases, the diminution of the coupling coefficient is smaller in response to changes in the value of "a" when it is changed to be become larger than 35 mm. For instance, when comparing cases in which the value of "a" are 22 mm and 38 mm, the coupling coefficient is higher by approximately 20% when the value of "a" is 38 mm. Further, when comparing cases in which the values of "a" are 20 mm and 40 mm, the coupling coefficient is higher by approximately 40% when the value of "a" is 40 mm.

As shown in FIG. **9**, in accordance with the antenna coil **11***a* separating from the metallic plate **133***a*, the Q value is monotonously increased, and particularly when the value of "a" becomes larger than 35 mm, which is, the antenna coil **11***a* does no more superpose the metallic plate **133***a*, the Q value abruptly increases.

The reason is that the more the antenna coil **11***a* separates from the metallic plate **133***a*, the more the metallic plate **133***a* is restricted of receiving the magnetic field which is generated by the current flowing through the antenna coil **11***a* and of converting the same into thermal energy such that the resistance value of the antenna coil **11***a* becomes seemingly smaller.

It can be understood from the above-described efficiency evaluation that the central portion **11***c* of the antenna substrate **11** shall substantially coincide with the end portion **133***b* of the metallic plate **133***a* in order to simply improve the coupling coefficient, it is required that both of a high coupling coefficient and a high Q value are consistent in order to achieve favorable communication properties. Accordingly, it is particularly favorable that the antenna coil **11***a* is disposed at a position which is proximate of the metallic plate **133***a* and at which it does not superpose the metallic plate **133***a* in view of establishing both, a high coupling coefficient and a high Q value so as to consequently obtain favorable communication properties.

In this manner, since the antenna module **1***b* and the antenna modules **1***a*, **1***c* and **1***d* according to the present example are disposed in that the antenna coil **11***a* is wound in the clearance **132** so as not to surround the outer peripheral portion of the metallic plate **133***a*, it is possible to achieve downsizing of the casing **131** when it is incorporated in an electronic device such as a mobile phone **130**. Further, the antenna module **1***b* and the antenna modules **1***a*, **1***c* and **1***d* according to the present example can realize favorable communication properties by utilizing magnetic properties by the metallic plate **133***a* opposing the reader/writer **120**.

MODIFIED EXAMPLE

As for antenna modules **1***b*, **1***c* and **1***d* from among the antenna modules **1***a*, **1***b*, **1***c* and **1***d* of the present example, it is possible to realize favorable communication properties while effectively utilizing the space of the clearance **132** by arranging the antenna modules substrate **11** to be inclined with respect to surface xy opposing the reader/writer **120** with the end portion **11***e* on the metallic plate **133***a* side being the central axis as shown in FIG. **10**. In this respect, a magnetic sheet **134** is provided to superpose the metallic plate **133***a* in FIG. **10** such that the metallic plate **133***a* does not reject the magnetic field from the reader/writer **120**. The angle of inclining the antenna substrate **11** with respect to the surface xy opposing the reader/writer **120** with the end portion **11***e* on the metallic plate **133***a* side being the central axis is defined to be θ.

Next, communication properties of the antenna coil **11***a* when the inclination angle θ is changed will now be evaluated.

Conditions of evaluation were as follows. Namely, the antenna **121** of the reader/writer **120** was a double-wound coil having an external form of 66 m×100 mm. The metallic plate **133***c* was an aluminum plate having an external form which is defined in xyz axial directions of 60 mm×45 mm×5 mm. The antenna coil **11***a* had a configuration with an external form of 40 mm×5 mm defined in xy axial directions with a magnetic sheet **13** being inserted into the central portion **11***c* and was a fourfold-wound coil. Moreover, the distance from the surface of the metallic plate **133***a* to the end portion **11***e* of the antenna coil **11***a* defined in the z axial direction was set to be 1 mm. Further, the distance from the end portion **133***b* of the metallic plate **133***a* to the end portion **11***e* of the antenna coil **11***a* which is defined in the y axial direction was set to be 2.5 mm.

Under the above-mentioned conditions of evaluation, coupling coefficients of "width: constant" wherein the shape of the antenna substrate **11** is constant and of "width: 1/cos θ" wherein the width from the end portion **11***d* of the antenna coil **11***a* to the other end portion **11***e* is changed in accordance with the inclination angle θ so as to satisfy "1/cos θ" are shown in FIG. **11**.

As shown in FIG. **11**, improvements in coupling coefficients can be seen when the inclination angle θ is inclined from 0 degree. In case of "width: constant", properties are highest at an angles of 25 to 30 degrees.

In case of "width: 1/cos θ", the width of the antenna coil **11***a* becomes larger in accordance with the increase in the inclination angle θ so that the coupling coefficient becomes higher. It is therefore preferable for the antenna coil **11***a* to set the width of the antenna coil **11***a* to be as large as possible within a range with which it can be accumulated in the clearance **132** when the antenna substrate **11** is inclined at inclination angle θ. For instance, when the region of the clearance **132** which is defined in a ZY surface in the inner structure of the casing **131** is substantially square, an angle θ of approximately 45 degrees is particularly suitable in view of effectively utilizing the space of the clearance **132**.

Properties of coupling coefficients under the above-mentioned conditions of evaluation when the shape of the antenna substrate **11** is constant and when the structure configuration of the antenna coil **11***a* is as that of the antenna modules **1***b*, **1***c* and **1***d* will now be shown in FIG. **12**.

As shown in FIG. **12**, properties are highest when the antenna coil **11***a* of antenna module **1***b* is inclined at an angle of 25 to 30 degrees while properties of the antenna coil **11***a* of antenna modules **1***c* and **1***d* are highest when it is inclined at an angle of 45 degrees and more.

Accordingly, while there are conditions for the angles that coupling coefficients become higher by setting large inclination angles θ for antenna modules **1***b*, **1***c* and **1***d*, particularly antenna module **1***b* is suitable from the aspect of effectively utilizing the space of the clearance **132** when the thickness of the clearance **132** which is defined in the z axial direction is limited in view of thinning.

In this manner, by arranging the antenna modules **1***b*, **1***c* and **1***d* such that the antenna substrate **11** is inclined with respect to the surface xy opposing the reader/writer **120** with the end portion **11***e* on the metallic plate **133***a* side being the central axis, it is possible to realize favorable communication properties while effectively utilizing the space of the clearance **132**. Further, when the thickness of the clearance **132** which is defined in the z axial direction is limited in view of thinning, particularly antenna module **1***b* is capable of realizing favorable communication properties while effectively utilizing the space of the clearance **132**.

EXAMPLE 2

A communication apparatus according to Example 2 adopting the present invention will now be explained. This communication apparatus is an electronic device incorporating therein the antenna module **1***a*, **1***b*, **1***c* or **1***d* according to the above-described Example 1. In the present example, concrete explanations will be made using a mobile phone **230** as shown in FIG. **13**.

More particularly, the mobile phone **230** comprises, similarly to the above-described mobile phone **130**, a battery pack **133**, and any one antenna module from among the antenna modules **1***a*, **1***b*, **1***c* and **1***d* within a casing **131** as shown in FIG. **13**A. The mobile phone **230** is here provided with a magnetic sheet **234** as to superpose a metallic plate **133***a* opposing a reader/writer **120** of the battery pack **133** so that a magnetic field is effectively drawn into the antenna coil **11***a* of the antenna module **1***a*, **1***b*, **1***c* or **1***d*. While the magnetic sheet **234** superposes the metallic plate **133***a* as described above for preventing the metallic sheet **133***a* from rejecting the magnetic field from the reader/writer **120**, it is further disposed, for more effectively drawing the magnetic field into the antenna coil **11***a*, in that an end portion **234***a* on the antenna coil **11***a* side extends towards the antenna coil **11***a* side so as not to superpose a surface opposing the reader/writer **120** of the antenna coil **11***a* opposing the reader/writer **120** as shown in FIG. **13**B.

The reason of not superposing the magnetic sheet **234** onto the surface of the antenna coil **11***a* opposing the reader/writer **120** is that superposing the same would unfavorably restrict the magnetic field that the antenna coil **11***a* receives.

In this respect, FIG. **13**B shows a structure configuration in which a magnetic sheet **13** is inserted into a central portion **11***c* of the antenna coil **11***a* of antenna module **1***b* from among the antenna modules **1***a*, **1***b*, **1***c* and **1***d* that are incorporated in the mobile phone **230**.

Communication properties of the antenna coil **11***a* will now be evaluated when the relative positions between the end portion **234***a* of the magnetic sheet **234** superposed on the metallic sheet **133***a* and the antenna coil **11***a* is changed.

Concrete conditions for evaluation were as follows. Namely, the antenna **121** of the reader/writer **120** was a double-wound coil having an external form of 66 m×100 mm defined in xy axial directions. The metallic plate **133***a* was an aluminum plate having a dimension of 60 mm×45 mm×5 mm. The antenna coil **11***a* was configured to have an external form of 40 mm×5 mm defined in the xy axial direction with a magnetic sheet **13** being inserted into the central portion **11***c* and was a fourfold-wound coil. Moreover, the distance from the surface of the metallic plate **133***a* to the end portion of **11***e* of the antenna coil **11***a* defined in the z axial direction was set to be 1 mm. Further, the distance from the end portion **133***b* of the metallic plate **133***a* to the end portion **11***e* of the antenna coil **11***a* which is defined in the y axial direction was set to be 2.5 mm. Further, a magnetic sheet **234** having a thickness of 0.1 mm was adhered onto the metallic plate **133***a* and its size in the width direction defined in the y axial direction was changed to obtain a coupling coefficient thereof. The coupling coefficients are shown in FIG. **14**. Here, there are shown in FIG. **14** changes in coupling coefficients when a width b defined in the y axial direction from the central portion **133***c* of the metallic plate **133***a* to the end portion **234***a* of the magnetic sheet **234** is changed in the range of 15 mm to 25 mm.

Here, since the width in the y axial direction of the metallic sheet **133***a* is 45 mm, the end portion **234***a* of the magnetic sheet **234** coincides with the end portion **133***b* of the metallic plate **133***a* when the value of b is 22.5 mm. When the value of b is 25 mm, the end portion **234***a* of the magnetic sheet **234** coincides with the end portion **11***e* of the antenna coil **11***a* and the end portion **13***a* of the magnetic sheet **13**, respectively.

As shown in FIG. **14**, when the value of b changes from 22.5 mm to 25 mm, the coupling coefficient of the antenna coil **11***a* abruptly increases in accordance with this change.

This is because the magnetic field that flows in parallel to the metallic plate **133***a* can be drawn into the antenna coil **11***a* via the magnetic sheet **234** without diverging the magnetic field proximate to the end portion **133***b*.

In this manner, since the end portion **234***a* on the antenna coil **11***a* side extends towards the antenna coil **11***a* side so as not to superpose the surface of the antenna coil **11***a* opposing the reader/writer **120** in the mobile phone **230**, it is possible to effectively draw the magnetic field into the antenna coil **11***a* so as to consequently realize favorable communication properties.

EXAMPLE 3

As described above, it is preferable to arrange the antenna coil **11***a* of the antenna module adopting the present invention proximate of the metallic plate **133***a* and at a position that does not superpose the metallic plate **133***a* in view of establishing both, a high coupling coefficient and a high Q value.

Here, when inductive coupling is to be performed with the reader/writer **120** through a magnetic field utilizing a transmission frequency of 13.56 MHz, the distance between the inner peripheral wall **131***a* of the casing **131** and the end portion **133***b* of the metallic plate **133***a*, which is, a width of the clearance **132** which is defined in the y axial direction is defined to be d [mm] as shown in FIG. **15**A. When this width d [mm] is changed, an area of the antenna coil **11***a* which is defined by the xy plane is fixed to be 300 [mm^2], and the width d−1 [mm] of the antenna coil **11***a* in the y axial direction is changed so as to substantially coincide with the width d [mm] of the clearance **132**, the coupling coefficients change as shown in FIG. **15**B. In this respect, evaluations are made using the antenna coil **11***a* of the antenna module **1***b* as a matter of convenience in FIG. **15**B.

As it is apparent from the results of FIG. **15**B, the coupling coefficient increases in accordance with the increase in width d [mm], which is, the width of the clearance **132** as well as the width of the antenna coil **11***a*, and the coupling coefficient becomes large with the peak being approximately 10.00 mm when the width d [mm] is approximately 8.00 to approximately 14.00 mm. While the coupling coefficient becomes large when the width d [mm] is in the range of approximately 8.00 to approximately 10.00 mm, improvement in the communication properties substantially saturate even if the width is increased to be larger than approximately 10.00 mm. Such properties are due to the fact that the periphery of the casing **131**, namely the magnetic force density of the clearance **132** is relatively large on the outer peripheral wall **131***b* side.

It is possible to realize favorable communication properties even if the width d [mm] is smaller than 8.00 mm. For instance, the antenna substrate **11** is disposed to be inclined with respect to surface xy opposing the reader/writer **120** with the end portion **11***e* on the metallic plate **133***a* side being the central axis as shown in FIG. **16**A. At this time, the angles θ of inclining the antenna substrate **11** with respect to the surface xy opposing the reader/writer **120** are defined to be 0 degree, 30 degrees and 45 degrees while the width d [mm] of the clearance **132** defined in the y axial direction is changed, the coupling coefficients change as shown in FIG. **16**B. In this respect, the shape of the antenna coil **11***a* is changed such that the end portions **11***d*, **11***e* coincide with the inner peripheral wall **131***a* of the casing **131** and the end portion **133***b* of the metallic plate **133***a*, respectively.

As it is apparent from FIG. **16**B, under such conditions, the coupling coefficient is optimized when the value of d [mm] becomes smaller, which is, the clearance **132** becomes narrower in accordance with the increase in the inclination angle θ.

As it is apparent from this result, it is possible to realize favorable communication properties by inclining the antenna substrate **11** even if the width d [mm] is smaller than 8.00 mm.

As it is apparent from the above-described results of FIG. **15**B and FIG. **16**B, the antenna coil **11***a* realizes a relatively high coupling coefficient when the end portion **11***e* on the metallic plate **133***a* side is not more than approximately 14.00 mm in the y axial direction which is perpendicular to the inner peripheral wall **131***a* when using the inner peripheral wall **131***a* of the casing **131** as a reference and to realize favorable properties while realizing downsizing of space in Example 3. More favorably, the antenna coil **11***a* realizes a particularly high coupling coefficient when the end portion **11***e* on the metallic plate **133***a* side is not more than approximately 10.00 mm in the y axial direction which is perpendicular to the inner peripheral wall **131***a* when using the inner peripheral wall **131***a* of the casing **131** as a reference and to realize favorable properties while realizing downsizing of space.

When the size of the substrate surface of the antenna substrate **11** which is incorporated in the mobile phone **130** is limited, it is preferable a define a width for the antenna coil **11***a* in the x axial direction while satisfying a condition for the position of not more than approximately 14.00 mm in the y axial direction which is perpendicular to the inner peripheral wall **131***a* when using the inner peripheral wall **131***a* of the casing **131** as a reference and more preferably of not more than approximately 10.00 mm in view of the following evaluation results.

For efficiency evaluation, the antenna substrate **11** disposed proximate to the metallic plate **133***a* and the reader/writer **120** were opposed as shown in the above-described FIG. **7**. The antenna **121** of the reader/writer **120** was a double-wound coil having an external form of 66 m×100 mm defined in xy axial directions. The metallic plate **133***a* was made of stainless steel having a dimension of 100 mm×50 mm×0.3 mm defined in xyz axial directions. The antenna coil **11***a* of the antenna module **1***b* was a fourfold-wound coil with external forms of 300 mm^2, 400 mm^2 and 500 mm^2 defined in xy axial directions in a condition in which the position of the end portion **11***d* on the inner peripheral wall **131***a* side of the antenna substrate **11** is substantially fixed at the position of the inner peripheral wall **131***a* of the casing **131**. Moreover, the distance from the surface of the metallic plate **133***a* to the surface of the antenna coil **11***a* defined in the z axial direction was set to be 1 mm. It should be noted that the angle θ of inclining the antenna substrate **11** with respect to the surface xy opposing the reader/writer **120** was defined to be 0 degree.

Changes in coupling coefficients when changing the ratio of the width in the x axial directional with respect to the width in the y axial direction of the antenna coil **11***a* (hereinafter referred to as "aspect ratio") under such conditions are shown in FIG. **17**.

In FIG. **17**A, the external form defined in the xy axial directions is defined to be 300 mm^2, in FIG. **17**B, the external form defined in the xy axial directions is defined to be 400 mm^2 and in FIG. **17**C, the external form defined in the xy axial directions is defined to be 500 mm^2.

In FIG. **17**A, rise in coupling coefficients saturates when the aspect ratio becomes larger than 3, while in **17**B, the rise in coupling coefficients saturates when the aspect ratio becomes larger than 4, and in FIG. **17**C, the rise in coupling coefficients saturates when the aspect ratio becomes larger than 5. In other words, this shows that the rise in coupling coefficients saturates even if the width of the antenna coil **11***a* in the y axial direction is made to be wider than approximately 10.00 mm.

As it is apparent also from this result, the antenna coil **11***a* can realize favorable properties while realizing downsizing in space when the end portion **11***e* of the metallic plate **133***a* is disposed at a position at which it is not more than approximately 14.00 mm in the y axial direction which is perpendicular to the inner peripheral wall **131***a* when the inner peripheral wall **131***a* of the casing **131** is used as a reference and more favorably of not more than approximately 10.00 mm. In this manner, in order to expand the area of the antenna coil **11***a* which is defined in xy axial directions with the aim of achieving improvements in communication properties, it is preferable that the width in the x axial direction is expanded while satisfying a condition in which the end portion **11***e* on the metallic plate **133***a* side is at a position which is not more than approximately 10.00 mm in the y axial direction which is perpendicular to the inner peripheral wall **131***a* when the inner peripheral wall **131***a* of the casing **131** is used as a reference.

Moreover, when the width of the clearance **132** in the y axial direction is limited to be not more than 8.00 mm, favorable communication properties can be realized by increasing the inclination angle θ of the antenna substrate **11** in accordance with the narrowness of the width.

In this manner, according to the antenna coil **11***a* of Example 3, it is possible to particularly improve properties per unit areas so as to realize an antenna module of small size, with little restrictions for mounting and of high competiveness.

REFERENCE SIGNS LIST

1 . . . communication apparatus; **1***a*, **1***b*, **1***c*, **1***d* . . . antenna module; **11** . . . antenna substrate; **11***a* . . . antenna coil; **11***b* . . . terminal portion; **11***c* . . . central portion; **11***d*, **11***e*, **13***a*, **113***b*, **133***b*, **234***a* . . . end portion; **111** . . . central axis; **12** . . . communication processing portion; **13**,**134**, **234** . . . magnetic sheet; **100** . . . radio communication system; **120** . . . reader/writer; **121** . . . antenna; **122** . . . control board; **130**, **230** . . . mobile phone; **131** . . . casing; **131***a* . . . inner peripheral wall; **131***b* . . . outer peripheral wall; **132** . . . clearance; **133** . . . battery pack; **133***a* . . . metallic plate; **133***c* . . . central portion

The invention claimed is:

1. An antenna apparatus which is incorporated in an electronic device and which is enabled to perform communication by receiving a magnetic field transmitted from a transmitter comprising:

an antenna coil which is wound in a clearance between an end portion of a conductive body opposing the transmitter within a casing of the electronic device and an inner peripheral wall of the casing so as not to surround an outer peripheral portion of the conductive body and which is inductively coupled with the transmitter;

wherein the antenna coil is disposed upon being inclined with respect to a surface opposing the transmitter with an end portion on the conductive body side being a central axis.

2. The antenna apparatus according to claim **1** , further comprising a magnetic sheet for drawing a magnetic field transmitted from the transmitter into the antenna coil,

wherein the antenna coil is formed by using a signal wire on a printed circuit board,

wherein the antenna coil and the magnetic sheet are superposed with respect to each other so as to satisfy both conditions of arrangement, namely a condition of disposing the magnetic sheet to be located further to the transmitter side than the antenna coil on a central side of a casing surface opposing the transmitter and a condition of disposing the antenna coil to be located further on the transmitter side than the magnetic sheet on the outer peripheral side of the casing surface with the magnetic sheet being inserted into a central portion of the antenna coil formed on the printed circuit board.

3. The antenna apparatus according to claim **1**, wherein the transmitter transmits a magnetic field having a transmission frequency of 13.56 MHz, and

wherein the antenna coil is disposed such that the end portion of the antenna coil on the conductive body side is at a position which is not more than approximately 14.00 mm in a perpendicular direction with respect to an inner peripheral portion when the inner peripheral portion of the casing is used as a reference.

4. The antenna apparatus according to claim **3**, wherein the antenna coil is disposed such that the end portion of the antenna coil on the conductive body side is at a position which is not more than approximately 10.00 mm in a perpendicular direction with respect to an inner peripheral portion when the inner peripheral portion of the casing is used as a reference.

5. A communication apparatus which is enabled to perform communication by receiving a magnetic field transmitted from a transmitter, comprising:

an antenna coil which is wound in a clearance between an end portion of a conductive body opposing the transmitter within a casing of the electronic device and an inner peripheral wall of the casing so as not to surround an outer peripheral portion of the conductive body and which is inductively coupled with the transmitters;

a communication processing portion which is driven through current flowing through the antenna coil for performing communication with the transmitter; and

a second magnetic sheet that covers a surface of the conductive body opposing the transmitter,

wherein the second magnetic sheet extends towards the antenna coil side such that an end portion on the antenna coil side does not superpose a surface of the antenna coil opposing the transmitter.

6. The communication apparatus according to claim **5**, further comprising:

a first magnetic sheet for drawing a magnetic field transmitted from the transmitter into the antenna coil.

7. The communication apparatus according to claim **6**, wherein the second magnetic sheet extends towards the antenna coil side such that a position of the end portion on the antenna coil side substantially coincides a position of an end portion of the first magnetic sheet on the conductive body side.

8. The communication apparatus according to claim **5**, wherein the transmitter transmits a magnetic field having a transmission frequency of 13.56MHz, and

wherein the antenna coil is disposed such that the end portion of the antenna coil on the conductive body side is at a position which is not more than approximately 14.00 mm in a perpendicular direction with respect to an inner peripheral portion when the inner peripheral portion of the casing is used as a reference.

9. The communication apparatus according to claim **8**, wherein the antenna coil is disposed such that the end portion of the antenna coil on the conductive body side is at a position which is not more than approximately 10.00 mm in a perpendicular direction with respect to an inner peripheral portion when the inner peripheral portion of the casing is used as a reference.

10. A communication apparatus which is enabled to perform communication by receiving a magnetic field transmitted from a transmitter, comprising:

a power supply portion;

an antenna coil which is wound in a clearance between an end portion of a conductive body opposing the transmitter within a casing of an electronic device and an inner peripheral wall of the casing so as not to surround an outer peripheral portion of the conductive body and which is inductively coupled with the transmitter;

a communication processing portion which is driven through power which is supplied from a battery for performing communication with the transmitter; and

a second magnetic sheet that covers a surface of the conductive body opposing the transmitter,

wherein the second magnetic sheet extends towards the antenna coil side such that an end portion on the antenna coil side does not superpose a surface of the antenna coil opposing the transmitter.

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